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Abstract

Green-GEAR aims at enabling and incentivising optimum green trajectories and airspace use through new ATM procedures; it develops three new SESAR Solutions to this end.

The present document is the final version of Operational Service and Environment Definition (OSED), providing the detailed description of the operational and technical environment associated with the SESAR Solution for Green route charging, targeted at achieving Technology Readiness Level 2.

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Authoring & approval

Author(s) of the document

Author	Organisation	Date
Sabine CAYRE	**EUROCONTROL**	19.06.2025, 13.09.2025
Tatjana BOLIĆ	**UoW**	20.06.2025, 16.09.2025

Reviewed by

Name	Organisation	Date
Fulvio VASCOTTO	**UNITS**	26.06.2025
Andrew COOK, Majid SOOLAKI	**UoW**	27.06.2025
Tobias BAUER	**DLR**	16.09.2025

Approved for submission to the SESAR 3 JU by[1]

Name, Function	Organisation	Date
Sabine CAYRE	**EUROCONTROL**	28.06.2025, 17.09.2025
René VERBEEK	**NLR**	27.06.2025
Tatjana BOLIĆ	**UoW**	28.06.2025, 17.09.2025
Lorenzo CASTELLI, Work Package Manager WP5 and Solution Leader Green RC	**UNITS**	28.06.2025, 17.09.2025
Tobias BAUER, Project Manager	**DLR**	30.06.2025, 17.09.2025

Rejected by[2]

Organisation name	Date

[1] Representatives of the participants to the project

[2] Representatives of the participants to the project

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The beneficiaries/consortium confirm(s) the correct application of the Grant Agreement, which includes data protection provisions, and compliance with GDPR or the applicable legal framework with an equivalent level of protection, in the frame of the Action. In particular, beneficiaries/consortium confirm(s) to be up to date with their consent management system.

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Green-GEAR

GREEN OPERATIONS WITH GEOMETRIC ALTITUDE, ADVANCED SEPARATION & ROUTE CHARGING SOLUTIONS

Green-GEAR

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1 Executive summary

The Green-GEAR project aims to develop innovative ATM (Air Traffic Management) procedures that enable and incentivise the use of optimum green trajectories and efficient airspace usage. This is achieved through a new SESAR Solution called Green route charging (GRC), specifically targeted at achieving Technology Readiness Level 2 (TRL2). It uses modulation of route charges, a mechanism enabled by the SES2+ regulatory framework, although not implemented yet. This document is the final OSED, building on the concepts presented in the initial OSED and the outputs of the subsequent validation exercises.

SESAR solution description: the Green route charging (GRC) Solution introduces new en-route charging mechanisms: Initial and Full. Initial Solution mechanisms are aimed at reducing CO_2 emissions and improving horizontal flight efficiency. These mechanisms give an early price signal to airlines to avoid congested airspaces at strategic level, thus promoting environmentally friendly flight paths. The Full GRC Solution investigates the possibility of reduction of total climate impact of aviation (both CO_2 and non-CO_2), through the incentivisation for avoidance of climate hotspots as defined by algorithmic climate change functions.

Operational and technical environment: the GRC Solution would be implemented within the 41 EUROCONTROL contracting States and adheres to the Multilateral Agreement on Route Charging. It specifically targets en-route airspace, influencing flight planning and route selection through economic incentives. The initial solution has no impact on operational processes at tactical level and the full solution which implies circumnavigation of climate hotspots[3], has limited impacts, outside the remits of the project.

Key assumptions: we assume that the modulation of route charges can effectively influence airlines flight planning to choose trajectories with lower environmental impact, whenever possible. The assumption on the efficiency of a price signal was validated by the results of the Green route charging simulations: 1.54% reduction of flown distance in the initial solution and reduction in number airspace violations, and about 14% reduction in total climate impact in the full solution.

Impact on stakeholders and performance contributions: the Solution impacts various stakeholders including States, Air Navigation Service Providers (ANSPs), EUROCONTROL's Central Route Charges Office (CRCO), the Network Manager (NM), airlines, Flight Plan Service Providers and MET providers. It aims to balance capacity supply and demand, enhance airspace efficiency, and ensure revenue neutrality for ANSPs.

Maturity Status: the concepts of the GRC Solution were validated through modelling and submitted to stakeholder consultation, with the aim of reaching TRL2. The Initial GRC Solution is at TRL2, while the Full GRC Solution reached TRL1 and TR2 ongoing status. Further developments, validations and stakeholder consultations will be required to reach higher TRL levels.

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[3] A climate hotspot is a volume of airspace where the atmospheric conditions are such that flying through it creates much higher climate impact (e.g. 95th percentile).

2 Introduction

2.1 Purpose of the document

The purpose of this Operational Service and Environment Definition (OSED) document is to provide a comprehensive description of the operational and technical environment associated with the SESAR Solution for Green route charging (Solution number 0408), targeted at achieving Technology Readiness Level 2 (TRL2). This document aims to outline the foundational elements required to understand and implement the Green route charging (GRC) mechanism, detailed insights into the operational scenarios, key assumptions, and the operational environment in which the Green route charging Solution targets [22]. GRC is designed to incentivise and enable optimum green trajectories and efficient airspace usage through innovative ATM procedures.

The SESAR Solution development lifecycle is structured to progressively increase the maturity of the Solution, with the ultimate goal of delivering it for industrialisation and deployment. The OSED is a critical technical deliverable at the TRL 2 stage, serving as a key reference for stakeholders involved in the Solution's development and future implementation. This document will facilitate the understanding and alignment of various stakeholders, including consortium members, SESAR project representatives, and regulatory bodies, by providing a clear and structured overview of the Solution's operational concept, technical environment, and expected performance benefits. It sets the stage for further validation and development activities that will be detailed in subsequent project deliverables and plans.

2.2 Scope

The scope of this OSED document is to provide a comprehensive description of the GRC Solution. This document delineates the new operating methods, the operational and technical environments, and the foundational elements necessary for the development and validation of the GRC Solution. These concepts are developed and assessed through the validation exercises as laid out in the Exploratory Research Plan (ERP) and detailed in the Exploratory Research Results (ERR) deliverable.

2.3 Intended readership

This document is aimed at the following stakeholders:

- All Green-GEAR consortium members who are contributing directly to the Solution research or contributing to related Solutions or work packages in the project (Airbus, DLR, EUROCONTROL, NATS, NLR, UNITS, UoW),
- Relevant SESAR projects,
- Relevant stakeholders,
- SJU Programme representatives, as the owner and final approver of this document.

2.4 Background

This section presents the background on which the Green-GEAR project is building, focusing on previous work and existing systems that have influenced the project's direction [21].

2.4.1 EUROCONTROL Route Charging System

The Green-GEAR project builds upon the existing EUROCONTROL route charging system, a regional cost-recovery mechanism adhering to ICAO's charging policies and the Single European Sky regulations [23] [24]. EUROCONTROL contracting States apply a regional common route charging system specifically for en-route charges. Initially based on historical costs, the system moved to forecast costs in 1983, introducing the concept of under and over recovery of costs. The establishment of the Single European Sky in 2004 emphasised transparency and economic regulation, leading to the adoption of the determined costs method alongside the existing full cost recovery method. In 2020, the calculation method transitioned from charging on filed route to charging on actual route flown, improving the cost-relatedness of revenue for ANSPs and enhancing airspace efficiency by eliminating incentives for filing optimised flight plans that are not always adhered to.

The purpose of the shift to actually flown route was twofold: to improve the cost-relatedness of revenue for the ANSPs and to increase predictability and efficient use of airspace. This change aimed to remove the incentive for airlines to file "route charges optimised" flight plans, which were not always adhered to and often led to less efficient use of airspace and reduced predictability for ANSPs.

2.4.2 Origin-destination charging

The project also incorporates elements from the Origin-destination charging (ODC) mechanism, which aims to eliminate detouring incentives. Unlike the common unit rate system, ODC allows ANSPs to control their unit rates and focuses on reducing CO_2 emissions compared to the current charging on actual route system. The ODC concept was originally published under the name FRIDAY (Fixed Rate Incorporating Dynamic Allocation for optimal Yield) [25]. ODC aims to ensure that route charges are more predictable and environmentally driven, providing a fixed charge for routes based on the great circle distance between origin and destination airports, thus reducing the incentive to detour for cost-saving purposes.

2.4.3 Previous Research Projects

This project builds on a foundation of prior exploratory research activities both within and outside SESAR and falls within the scope of the effort made by the European Green Deal, the overarching policy framework striving for climate neutrality by 2050, which emphasises reducing emissions across various sectors, including aviation. Notably, several significant past projects have laid the groundwork:

- **SATURN (Strategic Allocation of Traffic Using Redistribution in the Network)**: Focused on the modulation of en-route charges to redistribute traffic across Europe, providing initial insights into how pricing strategies can influence traffic flow [26].
- **ADAPT (Advanced Prediction Models for Flexible Trajectory-Based Operations)**: Explored advanced prediction models aimed at enhancing flexible, trajectory-based operations, providing a basis for adaptive decision-making in air traffic management.

- **Pilot3 (from Clean Sky 2)**: Contributed by integrating environmentally focused initiatives under the Clean Sky 2 umbrella, emphasising sustainability in aviation through innovative approaches and technologies.
- **COCTA (Coordinated Capacity Ordering and Trajectory Pricing for Better-Performing ATM)**: Provided an in-depth examination of coordinated capacity ordering and trajectory pricing, aiming to improve air traffic management (ATM) performance through strategic pricing and capacity management.
- **CADENZA (Advanced Capacity and Demand Management for European Network Performance Optimization)**: Focused on reducing air traffic emissions and improving overall network performance through enhanced demand-capacity balancing strategies.
- **ATM4E**: Explored the feasibility of a concept for environmental assessment of ATM operations, working towards environmental optimisation of air traffic operations in the European airspace, considering climate, air quality, and noise impacts.
- **CONCERTO**: Currently running, aims to make eco-friendly flight trajectories an everyday occurrence, reducing both CO_2 and non-CO_2 emissions from aviation by integrating green Air Traffic Control (ATC) capacities with appropriate automation.
- **GEESE**: Currently running, aims to develop an initial concept of operations for enabling Weather-Efficient Routing (WER) from Europe to the North Atlantic, analysing safety aspects and impacts on legacy systems.
- **CICONIA**: Currently running, focuses on reducing aviation's climate effects through innovative CONOPS, closely examining non-CO_2 effects and exploring methods to measure them.

These preceding and currently ongoing projects contribute valuable insights and methodologies that inform the development of this project's route charging mechanisms. They illustrate the use of pricing mechanisms to effectively manage air traffic and foster environmentally sustainable operations.

2.4.4 CLIMaCCF / FlyATM 4E and ALARM Projects

The consortium used the CLIMaCCF V1.0 Python library for defining climate hotspots, which is a product of the FlyATM 4E and ALARM projects [27]. This library computes individual and merged non-CO_2 algorithmic climate change functions (aCCFs) and is still under development and validation. These projects provide advanced climate science tools that allow the Green-GEAR project to address both CO_2 and non-CO_2 emissions in its route charging mechanisms. By leveraging these models, the project aims to enhance the accuracy and effectiveness of its environmental impact assessments.

2.5 Structure of the document

The Final OSED describes the GRC Solution for en-route air navigation services and constitutes project deliverable D5.4.

Section 2 (this section) provides the context for the project concept.

Section 3 is the main section that defines the GRC Solution, which is split into an initial Solution – for which 2 options are explored – and a full (longer term) Solution. The concept summary explores introduction of different options, highlighting their commonalities and specificities:

- Initial Solution: charging aimed at reducing CO_2 emission, with two methods:

- Modulation of route charges (MRC), that adjusts the charges to reduce CO_2 impact at flight/city-pair level, while addressing the airspace congestion.
- Combination of Origin-destination charging (ODC) with MRC, that establishes an identical baseline charge for all routes of a given city-pair, based on the Great Circle Path (GCP), on which MRC is then applied.

- Full Solution: charging aimed at reducing the combined effects of both CO_2 and non-CO_2 emissions.

The detailed concept describes the current charging mechanism, compares the current and future operating methods, and provides an overview of the future roles and responsibilities.

Section 4 states the assumptions under which the Solution is being assessed at this TRL level.

Appendix A defines the Benefit Impact Mechanism (BIM) for the concept, showing how the SESAR Solution contributes to the delivery of the expected performance benefits.

2.6 Glossary of terms

Term	Definition	Source of the definition
En-route charging zone	A volume of airspace that extends from the ground up to - and including - upper airspace, where en-route air navigation services are provided and for which a single cost base and a single unit rate are established.	Single European Sky (SES) performance & charging scheme
Unit rate	The unit rate of charge is the charge applied in a charging zone to a flight.	EUROCONTROL 2022
Route charge	The route charge is a levy that is designed and applied specifically to *recover the costs* of providing facilities and services for civil aviation.	ICAO Doc 9082
Cost base	The cost base for en-route charges consists of the determined costs related to the provision of air navigation services in the charging zone concerned. Determined costs are the costs determined by the Contracting States at the level of the charging zone. These are the costs to be shared among airspace users.	SES performance & charging scheme EUROCONTROL 2022
Environmental impact (EI)	The total emissions, CO_2 and non-CO_2, produced by a flight or a set of flights, measured in general in nK of increase of temperature at the 20 years horizon (called also ATR20).	Using CLIMaCCF [27] ATR calculations.

Term	Definition	Source of the definition
Environmental impact rate	The rate (euros per nK) at which the emissions at taxed in the full solution. This rate is set by a central agent like the Network manager.	
Modulation of charges	"Member States may, on a non-discriminatory and transparent basis, modulate air navigation charges for airspace users to: (a) optimise the use of air navigation services; (b) reduce the environmental impact of flying; (c) reduce the level of congestion of the network in a specific area or on a specific route at specific times; (d) accelerate the deployment of SESAR ATM capabilities in anticipation of the time period set out in the common projects referred to in Article 15a(3) of Regulation (EC) No 550/2004,… Member States shall ensure that modulation of charges in respect of points (a) to (c) of this paragraph does not result in any overall change in annual revenue for the air navigation service provider compared to the situation where charges would not have been modulated. Over- or under recoveries shall result in an adjustment of the unit rate in year n+2."	SES Performance & charging scheme
NWP	Numerical Weather Prediction – Forecast of the climate hotspots, that will be issued by the MET Offices. It can be used as an input by the GRC Full solution	ETS Regulation
Performance & charging scheme	Commission Implementing Regulation (EU) 2019/317 of 11 February 2019 laying down a performance and charging scheme in the single European sky [24] and repealing Implementing Regulations (EU) No 390/2013 and (EU) No 391/2013 (Text with EEA relevance.)	SES Performance & charging scheme

Table 1: Glossary of terms

2.7 List of acronyms

Term	Definition
aCCF	algorithmic climate change function
ANS	Air Navigation Services
ANSP	Air Navigation Service Provider

Term	Definition
ATC	Air Traffic Control
ATFCM	Air Traffic Flow and Capacity Management
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
AU	airspace user
CAPEX	Capital expenditure
CRCO	Central Route Charges Office
D<*no.*>	Deliverable <*no.*>
D	(delivery date)
DES	Digital European Sky
EC	European Commission
EI	Environmental impact
ER	Exploratory Research
ERP	Exploratory Research Plan
EU	European Union
GCP	Great Circle Path
GDPR	General Date Protection Regulation
Green-GEAR	Green operations with Geometric altitude, Advanced separation & Route charging Solutions
GRC	Green route charging
M<*no.*>	project month <*no.*>
MS<*no.*>	milestone <*no.*>
NM	Network Manager
NSA	National Supervisory Authority
NWP	Numerical weather prediction
ODC	Origin-destination charging

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Term	Definition
OPEX	Operational expenditure
OSED	Operational Service and Environment Description
RP	Reference period
SES	Single European Sky
SESAR	Single European Sky ATM Research
SJU	SESAR Joint Undertaking
SP	Stated preference
SRIA	Strategic research and innovation agenda
TRL	Technology Readiness Level
UK	United Kingdom [of Great Britain and Northern Ireland]
UKRI	UK Research and Innovation
WTP	Willingness to pay

Table 2: list of acronyms

3 Operational service and environment definition (OSED)

This chapter describes the Green route charging (GRC) [0408] Solution, for which the Initial and Full Solution have been developed and tested for feasibility [22].

3.1 SESAR Solution Green route charging: a summary

The **Initial Solution** proposes a novel route charging mechanism aimed at improving horizontal flight efficiency and reducing the resulting CO_2 emissions. The Solution addresses **route charging,** which is determined **strategically** with respect to flight planning**,** providing a price signal to AUs that encourages more efficient flight planning, environment and capacity -wise, also resulting in better predictability and optimised use of capacity for ANSPs. For instance, the solution incentivises trajectories that avoid congested airspace at peak times, and it removes the incentive of flying detours to avoid expensive airspaces.

CO2 emissions are assumed to be a proxy for flight distance. Vertical flight efficiency is not modelled at this TRL level. Other ATFM phases are not covered, as the setting of the unit rates for route charging is a strategic process that needs to be stable for at least a year of operations. The impact of the Solution on the daily operations is assessed during the validation exercises in this project, which will inform the further research needs for higher TRL levels.

From a regulatory perspective, the Solution must comply with the EU and ICAO rules and regulations (e.g. no discrimination, cost relatedness, proportionality, and revenue neutrality…) [23] [24].

Two options are explored in the Initial Solution:

- **Introducing a 'Modulation of route charges' (MRC) mechanism**, applied to the current trajectory-based route charges. Modulation factor M is determined for each route of a given origin-destination traffic flow, with the objective to reduce the environmental impact of flying, while addressing the airspace congestion.
- **Introducing an 'Origin-destination charging' (ODC) combined with the 'Modulation of route charges' (MRC) mechanism**, where ODC route charge is calculated on the Great circle path (GCP) between the origin and destination airports, therefore identical[4] for all routes of a given city pair, irrespective of the trajectory/distance flown. ODC establishes a simple reference for airspace users, with an identical baseline charge for all routes of a given city-pair. By construction, the ODC baseline aggregated at network level is a 'clean baseline' that does not include 'route charges optimised' trajectories and is therefore not biased by difference in trajectory lengths resulting from differences in unit rates. The modulation factor M_r that the

[4] Identical for the distance factor of the route charge, while the weight factor remains dependant on the aircraft's MTOW. See section 3.3.1 and 3.3.2 for more details on the current and new charging methods.

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MRC model produces for each route *r* of a given origin-destination traffic flow (as described above) is then applied to the ODC baseline.

The **Green Route Charging Full Solution** aims to incentivise the use of climate friendly trajectories, when considering both CO_2 and non-CO_2 emissions. The mechanism that rewards avoidance of climate sensitive areas (i.e. climate hotspots, determined by calculating the CO_2 and non-CO_2 combined effects), while still leaving the flexibility for aircraft operators of using the said areas, against a higher charge, and keeping revenue neutrality.

From a **regulatory perspective**, the Solution must comply with the EU and ICAO rules and regulations (e.g. no discrimination, cost relatedness, proportionality, and revenue neutrality…) [23] [24]. The Initial Solution may not need adaptations of the SES performance and charging scheme, which already contains provisions for modulation of charges for environmental purposes, except the inclusion of some post-operations analyses in the oversight activities. The new Central Planner role may need to be defined in the SES framework. Further, in the Full Solution, the KPI(s) for measuring the overall environmental impact of flights (including non-CO_2 impact) will need to be incorporated in the Performance and Charging Scheme.

The two options explored in the Initial Solution are:

- A **'Modulation of route charges' (MRC) mechanism**, applied to the current trajectory-based route charges. Modulation factor M is determined for each route of a given origin-destination traffic flow, to incentivise flight planning with the objective to reduce the environmental impact of flying, while addressing the airspace congestion.
- An **'Origin-destination charging' (ODC) mechanism combined with the 'Modulation of route charges' (MRC) mechanism**. As a first step, the ODC route charge is calculated based on the Great Circle Path between the origin and destination airports. The base charge is identical for all possible routes of a given city pair, irrespective of the trajectory/distance flown, therefore establishing a **simple reference** for airspace users.
  As a second step, a modulation **factor M_r** is applied to the baseline ODC charge of each possible route r of the city-pair, in order to smooth demand capacity balancing of sectors and airports.

Overall, the solution can be summarised as follows:

SESAR solution ID	SESAR solution title	SESAR solution definition	Justification (why the solution matters?)
0408	Green route charging	Charging mechanism that incentivises trajectories with minimum climate impact, while reducing airspace congestion.	The enabler for the European airspace to become the most environmentally friendly in the world, as set in the SRIA and the ambitions of the European Green Deal, and enables aviation to become more environmentally efficient [28] [29].

Table 3: Green route charging [0408] scope

On top of being a key enabler of the environmental ambitions set in the SRIA and the European Green Deal, the solution brings additional **operational benefits**:

- Airlines remain free to fly their preferred trajectory based on their business model.
- ANSP can benefit from better predictability, make a better use of available capacity, and potentially smooth a bit the workload peaks for their staff in congested periods.
- Preparing the economic modelling today and engaging early with stakeholders to ensure acceptance, will give the opportunity to anticipate and maximise the (cumulated) environmental benefits of the solution. Indeed, with the Full Solution, when the scientific basis is mature enough and when ATM has evolved to enable airspace users to avoid hotspots, the environmental benefits brought by the Solution could potentially be much higher when compared to the current measures targeting CO_2 emissions only.

3.1.1 Deviations with respect to the SESAR Solution definition

N/A

3.2 Detailed operational environment

3.2.1 Operational characteristics

The operational environment for the GRC Solution encompasses the 41 EUROCONTROL contracting States adhering to the Multilateral Agreement on Route Charging, specifically for *en-route charges*. These 41 contracting States include the 27 EU Member States.

The geographical scope is limited to en-route airspace. It is assumed that traffic, airspace, and airport characteristics are the same as today, as the GRC Solution can apply irrespective of the operational environment. The en-route charges in practice do not apply to flights with a maximum take-off weight (MTOW) below 2000 kg, military flights, flights in Visual Flight Rules (VFR) airspace, and circular flights.

The GRC Solution is developing a novel charging mechanism, which should change how the route charges are determined and charged, impacting the day-to-day operations only indirectly, through the modulation of unit rates.

3.2.2 Roles and responsibilities

The roles and responsibilities are described in Table 4.

Role	Responsibilities
National supervisory authority (NSA)	Develops national performance plans including local performance targets, determined costs, unit rates. Defines the charging zones. Reports yearly on the execution of the scheme and at the end of each reference period.
State	Consults ANSPs and airspace users on planned costs/investments and traffic forecast in preparation of Performance Plans. Adopts national performance plans including local performance targets, determined costs, unit rates. Calculates annually the unit rates for its en-route and terminal

Role	Responsibilities
	charging zones. May decide to apply modulation of charges. Takes the necessary measures to implement and enforce the scheme.
ANSP	For the establishment of the performance plan and unit rates, informs the NSA on the planned costs and investments, the traffic forecast, and its capacity plans. Reports annually to the NSA on actual costs, actual traffic, progress of planned investments, performance achieved on the Single European Sky (SES) 4 key performance areas (Safety, Capacity, Environment and Cost Efficiency). Provides actual traffic counts to CRCO in view of the calculation of the service units and charges.
European Commission	Adopts the Performance and Charging Scheme and subsequent revisions that govern the performance of Air Navigation Services. Adopts decisions on the Union-wide performance targets for safety, capacity, environment and cost-efficiency. Approves the national performance plans and corresponding targets, reports to the legislators on the implementation of the scheme.
Performance Review Body (PRB)	Advises the EC on the establishment of the Union-wide and local performance targets and on the assessment of the achievement of these performance targets.
EUROCONTROL - CRCO	The Central Route Charges Office (CRCO), on behalf of EUROCONTROL Members States, operates a joint system adopted by the Member States for the establishment and collection of route charges through a single charge per flight. The States signatories of the Multilateral Agreement relating to Route Charges, through the CRCO enlarged Commission and enlarged Committee, govern the Route Charges System. The CRCO calculates, in accordance with the applicable rules, the route charges due for each flight in the considered airspace. The CRCO collects the route charges and disburses the charges collected to the contracting States for the provision of the air navigation services (ANS), in accordance with the decisions of the enlarged Committee.
Central planner	The setup of modulation factors M requires an additional step to be added to the current system of route charging, which is running the GRC models (MRC or ODC+MRC) to determine the modulation factors. Furthermore, for the full GRC Solution, there is a need for a central entity that would provide the climate hotspot forecast and post-ops check inspection and check-up to make sure that the appropriate charge has been assigned to flights.

Role	Responsibilities
Network Manager (NM)	Optimises traffic flows by constantly balancing capacity supply and demand during all ATFCM phases.
Airline	Participates in the consultation of the EC and Member States on the implementation of the Performance and Charging Scheme. Plans and operates flights and pays the ANS charges invoiced by the CRCO.
Flight Dispatcher	The flight dispatcher is responsible for the planning of an individual flight by assessing of all boundary conditions (e.g. meteorological conditions, regulations, NOTAMs etc.) that impact the flight execution. The flight planning considers all external factors (route charges are just one component) and internal business policies and costs.
Computerised Flight Plan Service Providers (CFSPs)	CFSPs offer systems and services that assist airlines in the determination of the optimum flight trajectories in line with the airline cost/business model. These trajectories are updated in real-time to consider the evolution of the operational situation. Earlier in the planning process, OEMs develop sophisticated business planning tools (e.g. network / schedule / fleet planners). These tools must follow the evolutions of the regulatory and technological context.
MET providers	The MET providers issue weather forecast, or NWPs, which are needed for the definition of the EI charge (strategically) and to ease the flight planning by AUs tactically.

Table 4: Description of roles and responsibilities.

3.2.3 CNS/ATS description

Route charging uses already implemented CNS/ATM services. The actually flown trajectories are necessary for the calculation of route charges and their redistribution.

In the Initial Solution, the flight planning and flow management processes may be slightly affected (e.g. there may be a need for specific exchanges of capacity information between the ANSP/NM and the Central planner and adaptations in the AU flight planning systems), but it is not expected to have any effect on the operational control of the flight, and therefore no impact on CNS/ATS equipment.

In the Full Solution, there will be a need for monitoring of the actual situation concerning climate hotspots as opposed to the predicted one. This topic is outside of the Green-GEAR scope as it is currently assessing the feasibility and the benefits mechanism of the proposed solution. The monitoring should be assessed in the next steps.

3.2.4 Applicable standards and regulations

The current route charging system is subject to the following regulations and agreements:

- Commission Implementing Regulation (EU) 2019/317 of 11 February 2019 [24] laying down a performance and charging scheme in the single European sky and repealing Implementing Regulations (EU) No 390/2013 [30] and (EU) No 391/2013 (Text with EEA relevance.) [31].
- Regulation (EU) 2024/2803 of the European Parliament and of the Council of 23 October 2024 on the implementation of the Single European Sky (recast) – (the SES2+ regulation) [32].
    - EUROCONTROL's Multilateral Agreement relating to Route Charges.
    - ICAO's Policies on Charges for Airports and Air Navigation Services, 9th Edition, 2012, ICAO Doc 9082 [23].
    - Principles for establishing the cost-base for en-route charges and the calculation of the unit rates – EUROCONTROL.

3.3 Detailed operating method

3.3.1 Previous operating method

The EUROCONTROL's Central Route Charges Office (CRCO) implements the Multilateral Route Charging System and is responsible for calculation, collection, and redistribution of route charges.

Multilateral Route Charging System in the European Union is regulated by the Implementing Regulation IR 2019/317, the Single European Sky performance and charging scheme [24]. Here we shortly explain what the route charges are, and how the route charging system works.

Route charge "is a levy that is designed and applied specifically to *recover the costs* of providing facilities and services for civil aviation." (ICAO Doc 9082, 9th edition, 2012) [23] . The Route per State Overflown route charging system is applied in Europe, which implies that a flight needs to pay a route charge to each State crossed. Each State needs to establish one or more 'en-route charging zones'. The charging zone is a volume of airspace that extends from the ground up to, and including, upper airspace, where en-route air navigation services are provided and for which a single cost base and a single ***unit rate*** are established. Unit rate is a unique tariff per service unit. The number of service units for a flight is determined by the product of the distance and weight factors. Below, this is explained in more detail.

Route charge for a flight is a sum of charges accrued over all crossed charging zones *i.*

$R = \sum_i r_i, \qquad r_i = u_i * n_i,$

Where:

R is route charge;

r_i is a charge accrued over the charging zone *i;*

u_i is a unit rate for charging zone *i*; and

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$n_i$is the amount of service units "consumed", which are a product of the distance (d_i) and weight (w_i) factors.

$$n_i = d_i * w_i, \qquad d_i = \frac{GCD}{100}, \qquad w_i = \sqrt{\frac{MTOW}{50}}$$

Distance factor is proportional to the great-circle distance (GCD) between entry and exit points to each of the charging zones[5]. If the origin or destination airports are within the charging zone then the distance to be used equals GCD from entry point to the airport coordinates, minus 20 km (e.g., for arrival airport). The actual route flown as recorded by the Network Manager and is used as a basis for determining the distance factor.

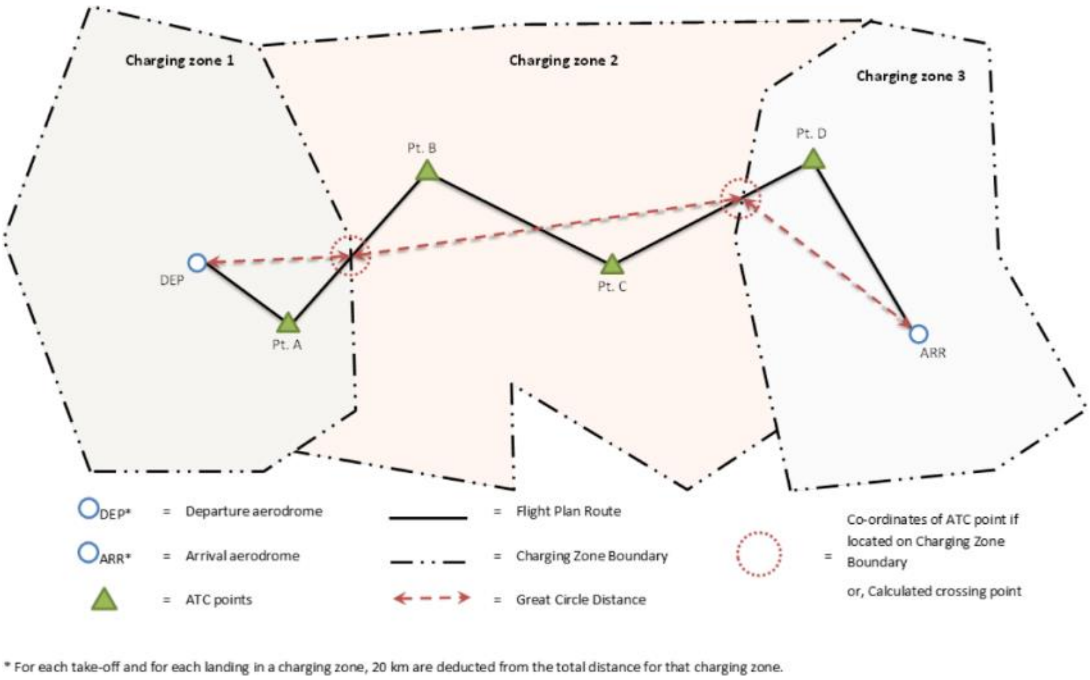

Figure 1 Establishing the distance factor for international flights (in current charging method).

The weight factor is introduced to relate the price to be paid for the air navigation services to the productive capacities of the aircraft. Therefore, heavier aircraft are expected to pay more for the air navigation services than lighter aircraft. The weight factor is less than proportional related to the maximum take-off weight of the aircraft.

IR 2019/317 sets the performance and charging scheme under the Single European Sky for EU Member States [24]. The regulation fosters long-term improvements in the ANS (Master Plan) [33], and

[5] This should not be confused with the GCD between the departure and destination airports, which is different for international flights.

reduction of green-house gas emissions and optimum use of airspace. The following terms are defined within the regulation:

- Reference periods,
- Performance plans,
- Network Manager (NM) performance plan
- Incentives,
- Route and Terminal charging schemes.

Reference period (RP) is the period of validity and application of the Union-wide performance targets, duration of which should allow the implementation of multi-annual capital expenditure programmes (usually 5 years). The purpose of the RP is to provide consistency and predictability by framing the forecast and planning activities of all actors concerned in the same time horizon.

The **performance plans** are prepared by the Member States' national supervisory authorities (NSAs), substantiated by evidence of ANS future cost (OPEX and CAPEX) and include the underlying assumptions (traffic forecast, inflation rate, etc.). The performance targets set for an RP remain unchanged during the whole period, except in exceptional circumstances allowing revision, subject to approval by the EC (e.g. variation of traffic forecast > or < by 10% compared to plan, over the period). The performance plans, need to provide transparency of determined costs, planned investments, and to be consistent with SESAR deployment and expected performance gains. The plan should list performance targets adopted (binding) and should contain: determined costs for en-route and terminal charges; description of incentive schemes, if any; and en-route and terminal traffic forecasts. The NSAs present a draft that the State adopts, that is then sent to the EC for assessment. After the plan is adopted by the EC, it should be adopted and published by the State.

NM performance plan: The Network Manager is also subject to performance targets that must contribute to the achievement of the Union-wide performance targets. It submits a Network performance plan which is verified and adopted by the EC. It also provides relevant inputs to target setting at Union, national and functional airspace block levels, and it supports the achievement of the Union-wide performance targets by proposing operational measures in the Network Operations Plan.

Incentives: The Performance and Charging Scheme foresees that "*performance targets should be subject to incentives with a view to encouraging better performance*"*.* These may be incentives of financial nature, for the achievement of the performance targets in the key performance area of environment. The scheme sets a capping on the value of these incentives as follows: The aggregated financial advantage or financial disadvantage from those incentive schemes shall not exceed 2 % of the determined costs of the considered year.

The Scheme also foresees that: *"Member States may, on a non-discriminatory and transparent basis, **modulate air navigation charges** for airspace users to: … reduce the environmental impact of flying; reduce the level of congestion of the network in a specific area or on a specific route at specific times…"* [24].

Modulation of charges cannot result in any overall change in annual revenue for the ANSPs. Over- or under-recoveries are corrected by an adjustment of the unit rate in year n+2. Member States must

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consult airspace users and ANSPs before the application of the modulation of charges (or any other substantial changes).

Charging scheme: The **charging scheme** describes the principles for determining charging zones (en-route and terminal charging zones) and unit rates. The **unit rates** are determined by dividing determined costs by the traffic forecast. Both determined costs and the traffic forecast are defined in the performance plan. Unit rates are calculated before the start of each year of RP, they should be established by November 1st and submitted to the EC.

The determined costs are the costs that are to be financed by charges imposed on airspace users. Their scope is strictly defined in the scheme: they are established by the NSAs based on the information received from the ANSPs, and after adoption, they are fixed for the RP period. Adjustments mechanisms are made possible under strictly defined conditions, upon NSA substantiated request and subject to approval by the EC.

The charging scheme also foresees that NSA need to define **traffic risk sharing** and a **cost risk sharing mechanisms** in case incentives schemes will be applied**.** Under the traffic risk sharing mechanism, the risk of revenue changes due to deviations from the service unit forecast (in practice deviation from traffic forecast) as set out in the performance plan, must be shared between ANSPs and airspace users. Under the cost risk sharing mechanism, differences between determined costs included in the performance plan and actual costs must be shared between ANSPs and airspace users.

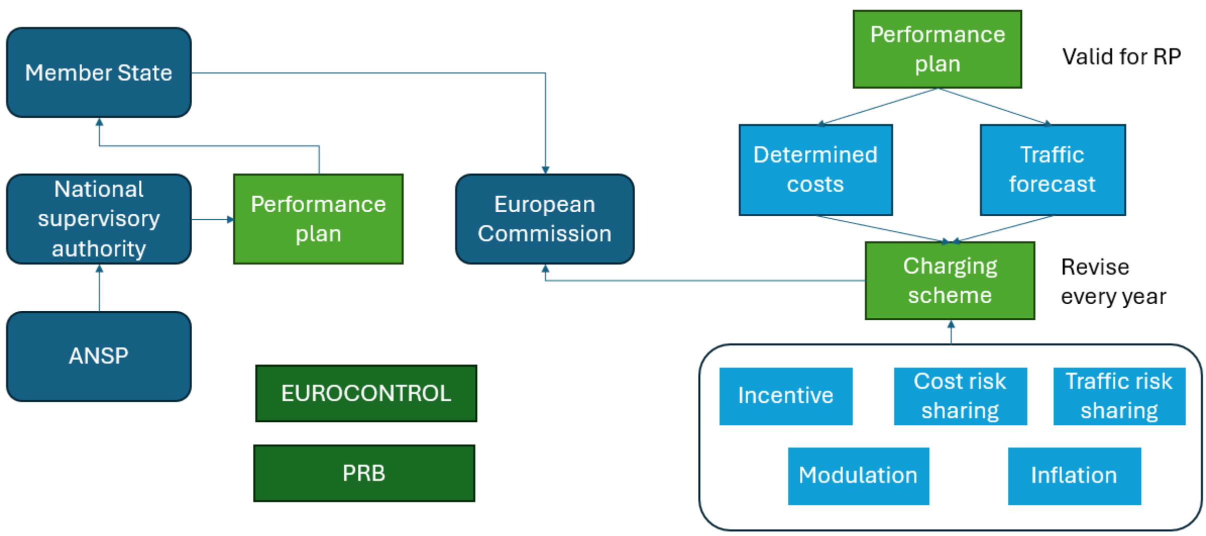

Figure 2 Performance and charging scheme stakeholders.

The latest event of relevance for the study concerning the Performance and Charging Scheme was the adoption of [Regulation (EU) 2024/2803](#) (the SES2+ regulation) on 23 October 2024. The regulation states that the Commission must conduct a **study** on the potential contribution of the modulation of charges to the achievement of the objectives of the Single European Sky, including environmental performance, together with a corresponding feasibility study. The results of the study will inform future Commission decisions concerning the uniform application of modulation of en route charges to support improvements in climate and environmental performance.

3.3.2 New SESAR operating method

General principles

The GRC Solution explores the Initial and Full options, where the initial one refers to the mechanisms that could be implementable earlier than those in the Full Solution, because not requiring significant regulatory adaptations and not depending on the outcomes of on-going research. All options must comply with the EU and ICAO rules and regulations.

The **Initial Solution** proposes two options for a novel **route charging mechanism** aimed to reduce, as much as possible, the **horizontal inefficiency** due to airspace congestions and difference in unit rates. The **Full Solution** looks at reducing **total climate impact of aviation.** The key additional function compared to the Initial Solution is that airspace users are also incentivised to avoid climate hotpots. These three options were modelled and tested in the same operational conditions, and their results are described in the ERR document [39].

Operational scope

The GRC Solution is primarily a **strategic concept aimed at influencing the long-term planning and operational strategies of airspace users**. It provides economic incentives through route charges to encourage the selection of environmentally friendly trajectories and optimal use of airspace. By adjusting route charges based on environmental impact and congestion, the GRC Solution aims to reduce CO_2 emissions and enhance airspace efficiency.

The operational environment encompasses the 41 EUROCONTROL contracting States that adhere to the Multilateral Agreement on Route Charging, specifically focusing on en-route charges. The GRC Solution is applicable to en-route airspace, where it can effectively influence flight planning and route selection. It does not apply to flights with a maximum take-off weight (MTOW) below 2000 kg, military flights, flights in visual flight rules airspace, and circular flights.

The operational environment covers the en-route airspace managed by the EUROCONTROL contracting States. The technical environment includes the existing framework of the SES performance and charging scheme and aligns with the principles set by the International Civil Aviation Organization (ICAO) [23].

The following stakeholders would be impacted and/or involved in the new process:

- **States:** Consult with air navigation service providers and airspace users (AUs), adopt national performance plans, calculate unit rates, and decide on the application of modulation of charges.
- **Air Navigation Service Providers (ANSPs):** Inform national supervisory authorities/States on planned costs and investments, report on actual costs and traffic, and provide traffic counts to CRCO.
- **EUROCONTROL's Central Route Charges Office (CRCO):** Operates the route charges system, calculates charges, collects and disburses charges, and supports States in the calculation of unit rates.
- **Network Manager (NM):** Optimises traffic flows by balancing capacity supply and demand, ensuring safe and efficient operations.

- **Airlines:** Plan and operate flights, pay route charges, and strive to reduce operating costs and environmental impact.
- **MET providers:** in case of Full Solution, an agreed forecast would need to be distributed to all involved stakeholders to be able to determine climate hotspots.

A new stakeholder role would be created: the **Central planner**, who would execute the computation tasks necessary to determine the modulation of route charges factors and the collection/dissemination of the related information to stakeholders involved.

The operational scope in terms of **ATM phases** varies with the options of the solution. In the Initial Solution, it is limited to the strategic phase, up to flight planning, complemented by some post-operations analyses that are not in the scope of this study. In the Final Solution, some ATFM measures may be developed in the pre-tactical/tactical phase to inform airspace users of changes in climate hotspots evolutions and to accommodate subsequent changes in flight plans/flown trajectories. This is not in the scope of the project either.

Methodology and validation

The GRC Solution employs a combination of hypothesis testing and solution searching methodologies. The initial concepts were developed and assessed through modelling and stakeholder consultations as is outlined in the Exploratory Research Plan (ERP) and reported in the ERR [39]. The validation exercises have tested the feasibility and effectiveness of the GRC mechanisms in realistic operational scenarios to ensure their robustness and scalability.

Research Questions and Hypotheses, as listed in the ERP:

- RQ1. Is there a way to reduce the climate impact of air traffic by changing the current route charging scheme?
- RQ2. How much can such a framework reduce the environmental impact of air traffic?
- RQ3. Can such a charging scheme be integrated in a framework which also considers congestion reduction?
- RQ4. How much can such a framework reduce the congestion?
- RQ5. Can the novel information on climate impact (both CO_2 and non-CO_2) be used in the route charging scheme, with the goal of reducing total climate impact of aviation.

The validation exercises provided initial responses to these questions, using representative days of traffic and surveying a sample of airspace users with diverse business models. Due to the high number of possible modelling parameters, simplifications in the assumptions were made necessary. Further research and development activities are needed to mature further the GRC Solution.

3.3.2.1 Modulation of route charges

The main idea is to introduce the modulation of route charges to reduce the environmental impact of flying, while also addressing congestion. The unit rate and the baseline route charge would be calculated in the same manner as in the current charging mechanism. The modulation of charges is expressed as a factor M_r, defined per *route r*, that reduces or increases the total route charge of that specific *route*.

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The goal is finding the set of M_r that maximise the reduction of CO_2 emissions, for which the global distance flown is taken as a proxy, while trying not to exceed the declared capacity of airports and sectors.

A *route r* is defined in a simplified way, as the list of (elementary) sectors crossed during the flight. Such simplification permits to group similar trajectories, which share the same modulation factor, in order, for the AUs, to have more flexibility within each *route*.

Figure 3 depicts how *routes* are taken into consideration. Sectors are shown as blue polygons. F1, F2, and F3 are three flight trajectories departing from O and arriving at D. F1 and F2 cross the same sectors and therefore could share the same modulation factor (although trajectories are quite different), F3 does not.

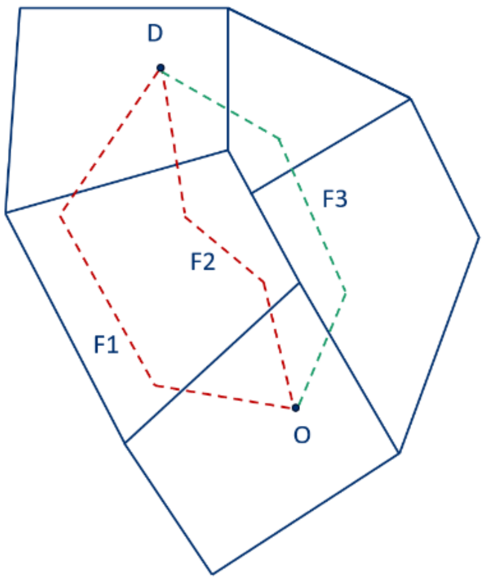

Figure 3 Identification of routes.

The calculation of unit rates that would be used in the route charges calculation would remain as of today but it would require the additional step of determining the modulation of route charges. The setup for collecting and distributing charges would remain the same as in the current charging mechanism.

The airspace users would know if the modulation of charges exists for different *routes* between origin-destination pairs of their interest, and they would be able to plan their routes accordingly. The route charge of a specific *route* would be equal to:

$$RC = BRC * M, \;\; where \;\; M_L < M < M_H$$

RC : route charge

BRC : baseline route charge

M : modulation factor. The factor can be constant for a yearly period, or it could vary across the day to reflect the congestion in the network.

M_L : lower limit of the modulation factor. Can be 0 if a limit is not required.

M_H : upper limit of the modulation factor. Can be defined or not specified.

Case 1: Applying incentives without capacity issue

The modulation factor would be primarily[6] needed on the longer routes that cross a series of States, which requires the collaboration of those States, as the individual decisions can have unintended consequences, like unaccounted traffic shift and/or congestion.

For example, in Figure 3, F3 may have decided to take the green trajectory because of lower unit rate, that compensate for the longer distance flown, with respect to the shorter red trajectories. Introducing the modulation factor, increasing the route charge for the green *route* ($M > 1$) and/or lowering the route charge for the red *route* ($M < 1$), it is possible to make longer trajectories inconvenient (economically), thus reducing the environmental impact.

Case 2: Applying incentivises with capacity issues

In case of foreseen congestion along the flight trajectory, the level of congestion/delay must be integrated in the parameters of the computation, when calculating the modulation factors. The modulation factors will incentivise the flights to avoid the congested sector(s), therefore smoothing demand-capacity balancing, improving operational efficiency with better use of available airspace, lower emissions and better predictability for the ANSPs.

Figure 4 MRC with two origin-destination pairs (red and blue), four route options and a congested sector shows a case where operating the shortest routes for 2 flights (red and blue flights) might lead to demand-capacity imbalances in some sectors (for example, here the hexagonal pink sector experiences congestion).

[6] A sector with capacity restrictions may also affect flights on short haul routes. However, these flights will have limited room for manoeuvre, due to the short distance/duration, therefore limiting the effect of the GRC incentive.

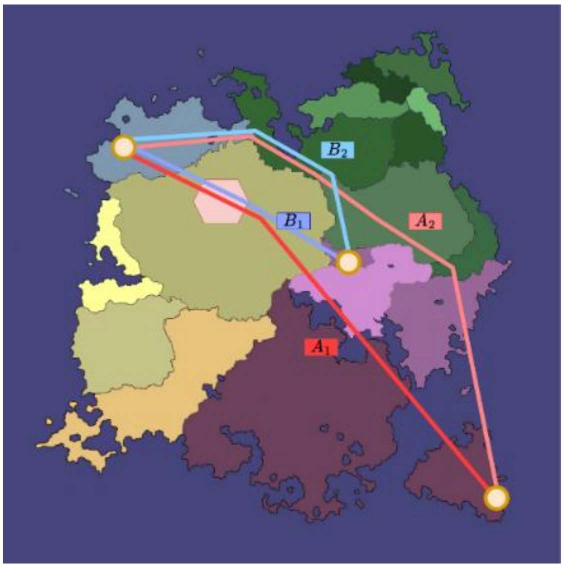

Figure 4 MRC with two origin-destination pairs (red and blue), four route options and a congested sector

Since capacity cannot always accommodate all traffic demands, some choices have to be made. In the example in Figure 4, a good solution from the environmental perspective could be to prioritise the red traffic flow by incentivising A_1, because it has the longest origin-destination distance, and, in order to avoid congestion, to redirect the blue flow on B_2. Also, when possible, another solution could be to indicate that the departures at certain times on certain ODs might suffer delay, which could also be a signal that incentivises the usage of the shortest route but, thanks to possible departure time adjustment without violating capacity constraints.

For this reason, in addition to the modulation factor, the Solution also gives the 'delay signal'. This indicates that on some routes, such a small strategic time shift could reduce additional delays and/or congestion.

The main outcome of this Initial Solution is a method for determining the values of M_r and the 'delay signal' (if any).

MRC Initial Solution and ATFM phases

Figure 5 illustrates the main functions of the MRC Initial Solution in the wider ATFM context, and the related information flows with stakeholders. This is valid for both options, MRC or ODC with MRC.

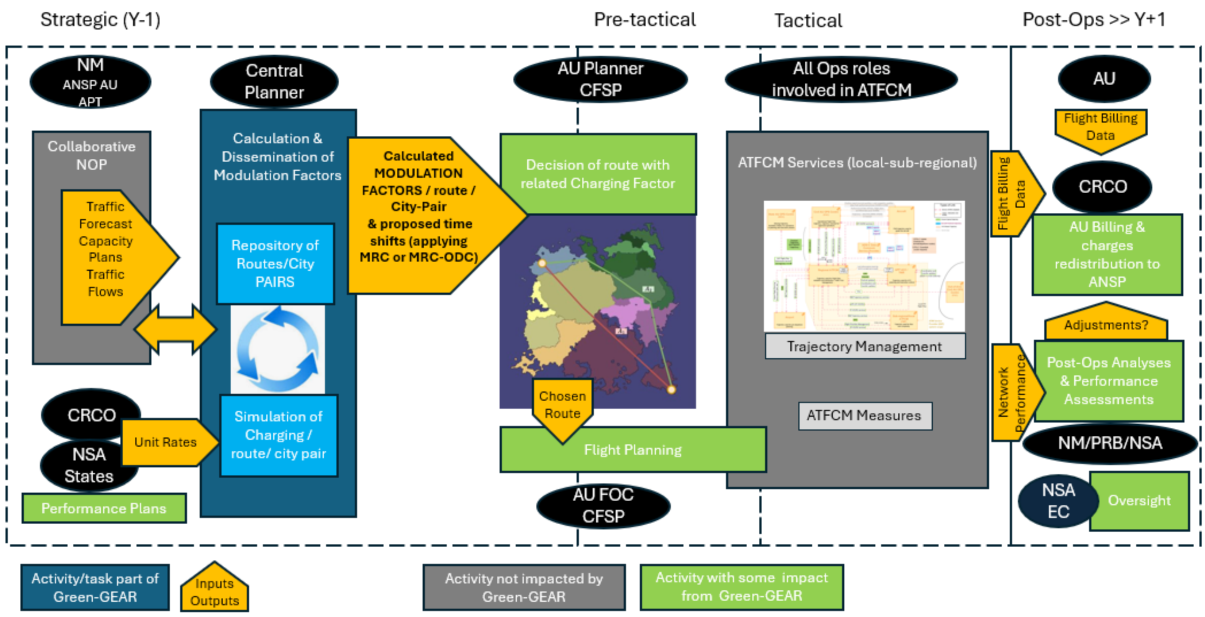

Figure 5 Green route charging [0408] Initial Solution - ATFM phases and stakeholders view

The Solution addresses the **route charging,** which is determined **strategically** with respect to flight planning. Other **ATFM phases** are not covered, as the setting of the unit rates for route charging is a strategic process that needs to be stable for at least a year of operations. The impact of the Solution on the daily operations was not assessed as such during the validation exercises in this project and may require further research at higher TRL levels. Post-operations analyses may be necessary, at stakeholder and flight level, at least in the transition phase, to establish confidence that all actors are treated fairly by the system. It was too early in TRL 2 to address such issues that should be a topic for further research.

3.3.2.2 Origin-destination charging (ODC) with Modulation of route charges (MRC)

In this second option of the Initial Solution, MRC is not using actually flown routes for the underlying base charging mechanism, but ODC. Below, ODC is first explained in more detail, and then it is explained how MRC in combination with ODC is different from MRC using current charging mechanism.

3.3.2.2.1 ODC

With ODC the charging mechanism is split between how the route charge is calculated for the AU, and how the revenue is redistributed among the ANSPs.

ODC uses the Great Circle Path between the origin and destination airports to determine the distance factors and unit rates to be used for calculating the route charge of the airspace user (AU). The ANSPs receive part of the generated revenue, in proportion to the service units they provided.

By design, the ODC base charge is independent of the route taken. Therefore, flight plan route optimisation is only focussed on fuel and flight time minimisation. This baseline aggregated at the network level is a 'clean baseline' that does not include 'route charges optimised' trajectories and is therefore not biased by detours as a result of unit rate differences.

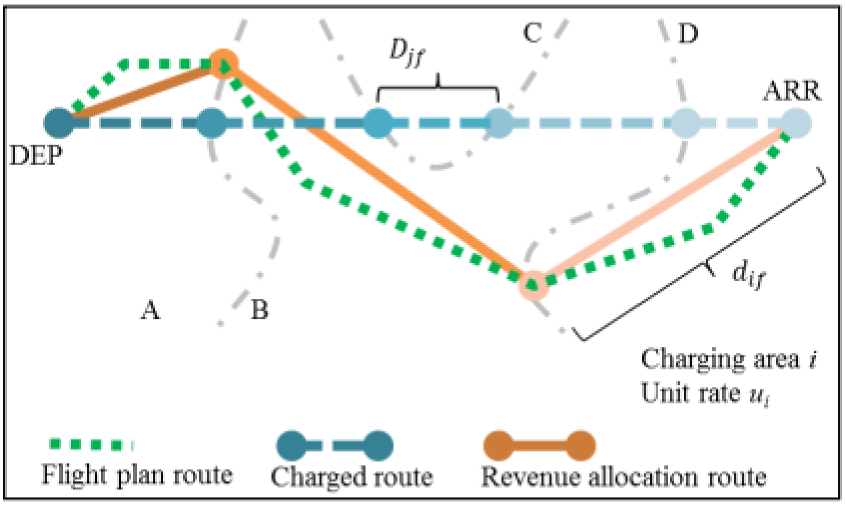

Figure 6 ODC: routes used for charging and for revenue allocation.

Route charge to be paid by AU

The route charge between a specific OD pair is the same for any chosen trajectory and is based on the Great Circle Path (GCP) between origin and destination. The GCP passes through charging zones with unique unit rates. The route charge is calculated based on the section lengths along the GCP, the weight factor, and the unit rates of the intersected charging zones along the Great Circle Path. This determines the total route charge to be paid for a given city-pair and aircraft type.

The route charge R_{jf} for the section *j* of the GCD is calculated in the following way for aircraft *f*:

$$R_{jf} = D_{jf} \cdot p_f \cdot U_j$$

where D_{jf} is the distance factor covered by the GCD from origin to destination crossing the charging zone *j*. U_j is the unit rate applied in the charging zone *j*. The weight factor p_f is dependent on the MTOW and is assumed to be identical to the weight factor currently being used by EUROCONTROL Member States.

The total route charge to be paid for aircraft *f* is:

$$R_f = \sum_j R_{jf}$$

Charging zone revenues

The collected charges are proportionally divided over the charging zones actually crossed. The proportionality is based on the route charge according to EUROCONTROL actual route flown (or planned).

The share S_{if} from the total charge paid by aircraft *f* that is allocated to charging zone *i* is:

$$S_{if} = \frac{r_{if}}{r_f}$$

With r_{if} being the individual charge as a function of the service units and the unit rate for the charging zone:

$$r_{if} = d_{if} \cdot p_f \cdot U_i$$

And r_f being the total charges r_{if}:

$$r_f = \sum_i d_{if} \cdot p_f \cdot U_i$$

The amount a route charging zone *i* is allocated from the collected charges from a flight is $R_f S_{if}$. The total amount each route charging zone *i* is allocated over all flights is:

$$R_i = \sum_f R_f S_{if}$$

Determining unit rates

The definition of the state-by-state unit rate would need to be changed, as the calculation of the ODC rate would need to be performed in collaboration, centrally.

The unit rates are set such that the periodic costs c_i of providing the air navigation services equals to the expected amount of revenue within that period.

With the weight factor being equal for all EUROCONTROL Member States, the cost for each charging zone must be set equal to the expected revenue resulting in the equation:

$$c_i = U_i \sum_f \frac{\sum_k D_{kf} U_k}{\sum_j d_{jf} U_j} d_{if} p_f$$

Using a numerical method (e.g. Newton method using difference formulations) the set of equations can be solved to get the set of unit rates U_i. This method converges quickly to a stable set of unit rates.

3.3.2.2.2 Applying MRC to ODC

The first step was to determine the baseline for charging, using ODC, as defined above. The same ODC base charge is used for all route options of a given flight between the origin and destination airports. ODC has a positive effect on the CO_2 emissions of flights, as the flight trajectory is optimized in terms of fuel and time only. ODC as such does not take airspace capacity constraints into account.

The second step is then to apply MRC to the ODC baseline charge. The modulation of charges - expressed as a factor M, defined per route, that reduces or increases the total route charge of that specific route – generates an incentive to avoid congested areas/time periods.

The route charge is calculated in a similar way as with the original MRC concept:

$$RC = ODC * M, \; where \; M_L < M < M_H$$

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where ODC is the baseline route charge according to the ODC mechanism.

ODC and MRC can be applied to the example in Figure 6. Due to the application of ODC the base route charge for all three route options F1, F2 and F3 is equal to the ODC route charge. If there are no constraints, and the charge for all three options is equal to ODC, the shortest route will be chosen. In this case it would be F2. But if the demand is too high on the sectors F1/F2 are passing through, the modulation factor M for F1 and F2 can be adjusted to make these route options less attractive compared to F3.

(ODC-MRC) Initial Solution and ATFM phases

See Figure 5 for an overview of the main functions of the **(ODC-MRC)** Initial Solution in the wider ATFM context, and the related information flows with stakeholders. This is valid for both options, MRC or ODC with MRC.

3.3.2.3 Full GRC Solution

The general scientific problem we face here is to forecast the impact of a change of policy, i.e. route charges, when flights are crossing climate hotspots, on the airlines' behaviour when planning/choosing trajectories and their related climate impact. This is crucial to be able to find a policy that may, in fine, lead to a reduction of climate impact.

Such forecast is not easy to form, since 1) traffic patterns can change for various reasons; and 2) airlines have intricate and heterogenous decision-making processes that may lead to counter-intuitive results. For Full GRC Solution, we focus on the second issue, leaving the exact traffic forecast to entities with better forecasting capabilities, like STATFOR. Here, we assume that airlines minimise a utility function when choosing their flight plans pre-tactically. This utility function is composed of the parameters which can be sorted out in two big categories, delay and cost, with added category for the environmental impact.

Hence, the core policy idea is to identify climate hotspots, either strategically or tactically and put a modulated charge on top of the standard route charges on the trajectories going through hotspots, to de-incentivise their choice. The extra revenues coming from the modulation may then be offset by a decrease of the route charges at a strategic level to ensure revenue neutrality for ANSPs.

Given a modulation scheme and an offset mechanism, the task is then to forecast how much airlines will avoid the hotspots, keeping in mind constraints linked to capacity. This can be done via two methods:

- An analytical and semi-analytical model: the mathematical expectations of EI and other metrics are computed explicitly, taking into account the utility functions and the stochasticity of the environment (for instance, the appearance of hotspots). These models are typically very fast to execute, but may struggle to take into account all constraints/behaviours happening in the system. Moreover, the implementation effort may scale badly with the number of routes and different types of airlines.
- A bi-level optimisation model, used within a Monte-Carlo scheme to estimate the expectation from the policy implementation. This type of model can be slow to execute but is able to capture many details that analytical models sometimes cannot. The implementation effort is also fairly low in this case, and does not depend on the number of OD pairs simulated.

The full GRC is interested in setting strategically modulation levels that will be applied tactically, akin to how ANSPs compute their unit rates for the next reference period. Hence, the level of details at the tactical level may be enough in the analytical model to capture most of the impact that we want to see from the mechanism. This is the method we are using in both exercises.

Goal

The model presented is a simple one designed to show the main trends that can be expected when applying the Full Solution. As a reminder, the full solution consists in the following process:

- At the start of a reference period (e.g. every 5 years, or every year), the Central planner decides the 'environmental impact tax rate' (EI rate).
- X hours before a flight plan (e.g. 6 hours, typically on the same time scale than weather forecast), the Central planner defines environmental "hotspots", in the form of 3D volumes.
- Any flight going through a hotspot has to pay an extra charge in the form of the distance flown through the hotspot times the EI rate.

The model presented here aims at answering the following questions:

- Given a traffic forecast at the beginning of the reference period and an EI rate, what is the expected impact of the EI rate on the behaviour of airlines, without considering capacity issues, and what is the resulting impact on the KPIs? (see Table 11). This prediction is called the 'free' prediction in the following, because it does not take into account capacity optimisation of EI impact.
- Similarly, what is the impact of the EI rate given capacity constraints? This prediction in the following is called the 'capp' prediction. It takes into account various capacity constraints.
- Finally, how much should the EI rate be to minimise the environmental impact? What is the impact of this rate? This prediction in the following is called 'full'.

Figure 7 Example of climate hotspot and different trajectory possibilities.

In order to formulate this Solution, the Green-GEAR project launched a stated preference (SP) survey aimed at assessing the AUs' willingness-to-pay (WTP) for the reduction of climate impacts, taking into account flight operational characteristics, such as risks of delay occurrence, costs and environmental impact. Climate hotspots and the willingness-to-pay of different airline types were used in the modelling to assess the feasibility and potential benefits of the full GRC Solution.

Figure 8 Example of Full Solution validation scenario.

Full Solution and ATFM phases

Figure 9 illustrates the main functions of the GRC Full Solution in the wider ATFM context, and the related information flows with stakeholders.

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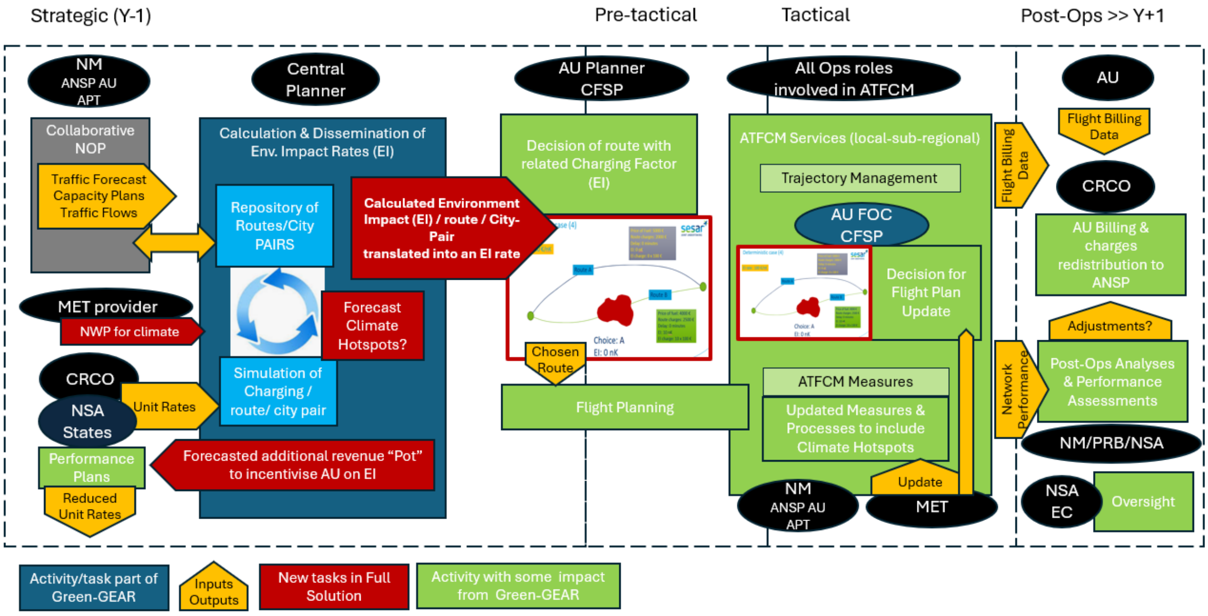

Figure 9 Green route charging [0408] Full Solution - an example of ATFM phases and stakeholders view.

In Figure 9, the functions in red are the new functions introduced compared to the Initial Solution. They include processes for:

- collecting (climate-related) weather forecasts,
- forecasting the occurrence and position of these climate hotspots on traffic flows,
- calculating EI rates for each route based on the expected environmental impact
- assess the monetary value of the total incentive to be allocated system-wide.

3.3.2.4 Use cases

The use cases presented below are not supposed to cover exhaustively all aspects of the Solution but are considered to be the most relevant to describe how the Solution impacts the business and strategic operations planning activities of the stakeholders involved. The process starts with the collection of the information necessary to feed the system that determines the new route charging mechanism. It ends with the AU's decision to file a flight plan that takes into account the new route charges.

The three options/mechanisms each represent a use case. The stakeholders are the same across the three use cases and share most of the actions (with the addition of MET provider in Full Solution). The main changes are presented through the new stakeholder – Central planner. The Central planner delivers the new functions in each use case. These new functionalities are the subject of the assessments in the Green-GEAR project, while the functions of the other stakeholders are here for having the complete picture on the overall processes, and have not been assessed per se.

The MRC use case is depicted in Figure 10, the ODC+MRC in Figure 11 and Full GRC Solution in Figure 12.The text below describes the roles and functions of various stakeholders, the variations across the use cases are described, where such differences exist.

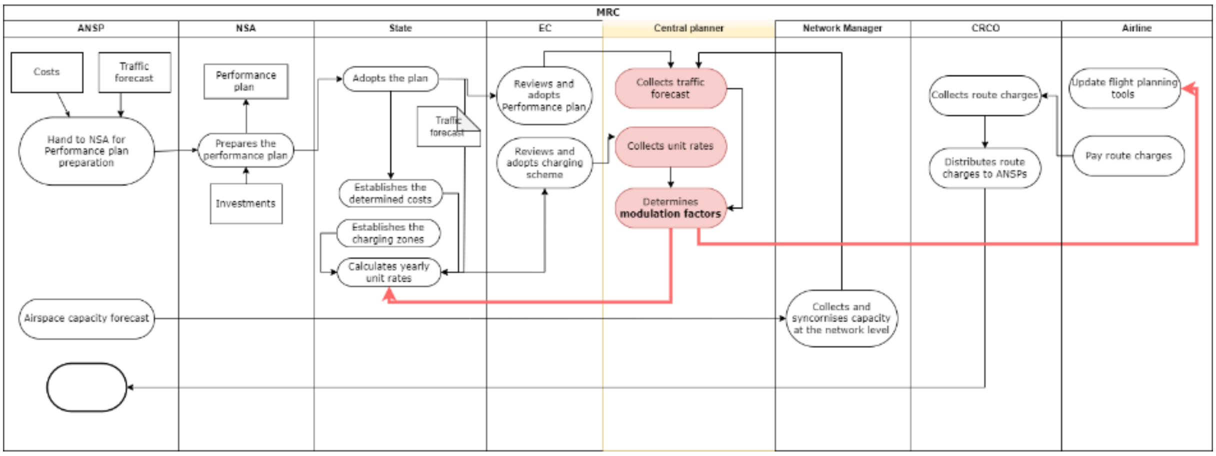

Figure 10 MRC use case.

European Commission and States. The EC and the States will have an essential role in the establishment of the route charging mechanism and its oversight. This will require the revision of the SES performance & charging scheme. For the EC, this means inter alia conducting the regulatory impact assessment of the new charging mechanism, evaluating if this incentive scheme is “effective and setting parameters in a non-discriminatory and transparent manner”. This also includes setting up the corresponding stakeholder consultation arrangements and submitting the new text to the co-legislators in view of the adoption. For the States, represented by their NSAs, this means conducting an impact assessment at national level, organising the corresponding stakeholder consultations, and agreeing with their peers on a coordinated implementation EU-wide.

If the new charging scheme is adopted, the EC and the States will also have to conduct additional activities that are specific to the chosen option:

- **MRC:** When establishing their performance plan, ahead of a new reference period, the NSA will have to include yearly unit rates that are calculated by applying on the actual trajectories, the modulation of charges factors generated by the Central planner. The plan will include a justification of the impact of these modulation factors on the ANSP revenues, and on the ability of the ANSP to deliver the air navigation services with the expected performance levels (e.g. capacity). The EC, when approving the cost efficiency performance targets submitted by the State, will validate that the impact of the modulation of charges incentive is correctly reflected into these targets. When reporting on the yearly application of the performance and charging scheme, the NSA will need to exercise a specific scrutiny on the impact of the application of the new charging mechanisms, e.g. by comparing it to the previous charging system. The EC may have to exercise the same level of scrutiny when assessing the yearly implementation of the performance and charging scheme (by validating that the modulation of charges incentive is correctly reflected into the actual unit rates and actual charges incurred by airspace users).
- **ODC+MRC:** The tasks involved by the ODC+MRC charging option are the same as in the MRC option, with one difference: the baseline charges to which the MRC applies is not calculated from the actual trajectories but from the ODC trajectories. The setup of ODC baseline charges should in itself be coordinated and agreed upon by the States and EC

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- **Full GRC application:** In addition to the tasks described above, and before the implementation of such a mechanism, the EC and the NSA may have to assess and validate the mechanism that will underpin the GRC, for calculating the combined climate impacts of CO_2 and non- CO_2 emissions, based on scientific evidence and testing the impact on daily operations of AUs and ANSPs.

NSAs and the PRB. NSAs and the PRB must integrate the modulation of charges mechanism in their works when determining – and assessing, respectively – unit rates and performance targets. They also need to be involved in the post-operations analysis of the MRC (or ODC+MRC) mechanism, its impact on flight efficiency and ANS capacity, in particular during the transition period when stakeholder consultation will be critical to ensure proper implementation.

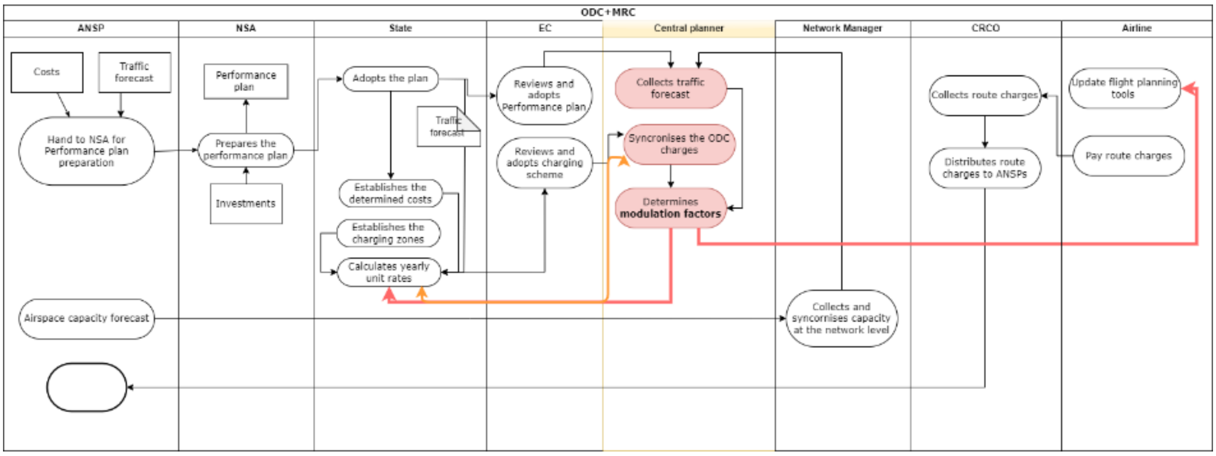

Figure 11 ODC+MRC use case.

Central planner, is a new stakeholder/function. On a yearly basis, the Central planner collects information to forecast the demand and the expected operational network situation of year N+1: traffic forecasts with modelling of flight distribution across the ANSPs, capacity plans at ANSP level (declared capacity) and identification of congestion areas. It is assumed that this process would build on the NOP planning process that is already in place and collects similar information from established ANSP contact points. The Central planner also coordinates yearly with EUROCONTROL/CRCO to collect the service units reported by the NSAs and approved by the EC.

The Central planner feeds the MRC/ODC+MRC modelling system with these yearly updated figures (traffic forecast, capacity forecast, unit rates), see Figure 10 and Figure 11. From there and from historical traffic, the model simulates the interactions between the actors involved in the airspace considered, and calculates the modulation factors (M), that are shared and coordinated with the States to be included into the charging scheme. The approved charging scheme is then shared with the AUs.

In case of the Full GRC Solution, Central planner in addition collects the weather forecasts over the entire year which are then used to determine the EI modulation, and to offer a tool that produces the daily climate hotspots for flight planning and route charging purposes. This would be needed so that all the stakeholders can have the same information for planning and charging.

Airlines. With the MRC and ODC+MRC mechanisms, airlines receive an early price signal alerting on risks of congestion/delay. The modulations need to be incorporated in their flight planning tools. With the Full Solution, the EI modulation is determined once a year, but the climate hotspot, or weather forecast is needed to be able to include the climate hotspots in the flight planning.

CRCO. Overall, for the MRC and ODC+MRC, the mandate/activities of the CRCO remain unchanged: calculation and collection of routes charges and transfer of the charges collected from the AU by redistributing them to the ANSPs.

MET providers produces a common weather forecast to be used for climate hotspot forecast (see Figure 12).

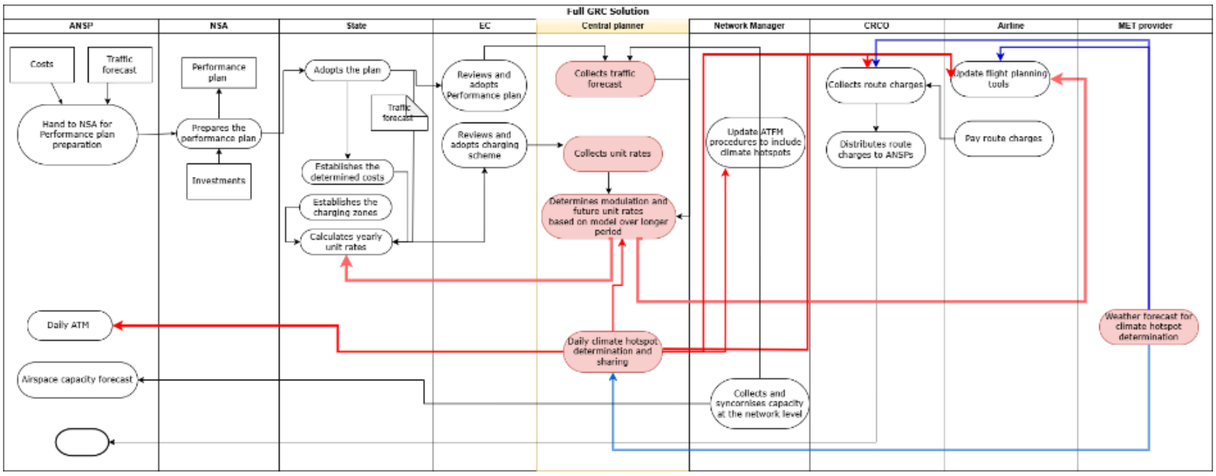

Figure 12 Full GRC use case.

ANSPs and Network Manager. The ANSPs and the Network Manager cooperate with the Central planner to maximise the accuracy of the capacity forecast.

In the Full GRC Solution, there might be a need for the Network Management functions to incorporate the avoidance of climate sensitive areas into the Collaborative Decision Management (CDM) operational processes. This includes the adaptation of the role of the Network Manager to the application of the avoidance of climate sensitive areas.

3.3.3 Differences between new and previous operating methods

Activities (in the SESAR architecture) that are impacted by the SESAR solution	Current operating method	New operating method
Strategic and tactical planning of AU operations	Flight Schedule Planner, Airline Operations and Control Centre (AOCC) plan and operate flight	Incorporates the Modulation of Charges into their price model and their FMS. Adapts flight planning decisions accordingly (schedule, trajectory)
Network Operations / ATFCM	ATFCM is responsible for the demand and capacity balancing activities.	Supports the Central planner in the capacity and demand forecast, which may involve a reinforcement of the current ATFCM processes

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MET services	*Provide scope of weather data relevant to the ATM stakeholders **Noting that these services may also be delivered by another player*	Extend services to the forecast of climate hotspots in strategic phase and their detection in pre-tactical/tactical phases (only applicable to the GRC Full Solution). The distribution and consistency of enhanced / new MET information exchanges will be via standardised services. (e.g. information provided by Solutions 419, 420, 421, 374.)
Activities (NOT in the SESAR architecture) that are impacted by the SESAR solution	**Current operating method**	**New operating method**
Planning & oversight of performance and charging (by EC & States)	In line with the tasks described in the Performance and Charging Scheme	Include a step for the validation of the Modulation of charges mechanisms, both at planning and oversight level
Central determination of modulation of Charges (by Central planner)	Does not exist today. Modulation of charges is allowed at State/Charging Zone level but does not take place in practice	The Central planner defines the Modulation of Charges values to be applied at route level at strategic planning stage.
Collection and disbursement of en-route charges	In line with the 'EUROCONTROL Principles for Establishing the Cost-Base for En-Route Charges and the Calculation of the Unit Rates' and the Performance and Charging Scheme	Incorporates tasks to support the Central planner for the simulation of the Modulation of Charges values and to support the NSAs in the determination of the resulting Unit Rates

Table 5: Differences between the new and the previous operating method

4 Key assumptions

4.1 Operational assumptions

The **GRC Initial Solution**, being a relatively simple change in the route charging mechanism will not have a direct impact on daily operations. The indirect impact could be seen in a traffic redistribution following the changes in the route charge amounts – i.e., the change in price can change the choice of specific trajectory when cost minimisation is used for flight planning.

The **GRC Full Solution** might have an impact on the operations, in following terms:

- As it is based on awarding the avoidance of climate hotspots, which depend on the changing state-of-the atmosphere, the traffic flow changes might become rather dynamic. This could prove to be difficult to manage, as the forecast window would be less than a day (as weather forecasts need to be used for climate hotspot identification). This aspect will be only partially addressed at this TRL level, mainly checking if its introduction at the network level would be feasible at all.

- All stakeholders (e.g., controllers, AUs, NM) would need to have the same baseline information on the climate hotspot prediction, to be able to predict the place and time of worse areas, and thus the forecast of possible traffic re-distribution.

4.2 Performance assumptions

The GRC Solution impacts the following key performance areas (KPAs) [1]:

- **Capacity**. As determination of modulation of route charges takes into account the airspace (and airport capacities for the Initial Solution), it is expected that the demand capacity imbalances will decrease. This was confirmed for the **Initial Solution** through validation exercises. The testing of the MRC model allowed indeed a reduction of more than 99% of the number of capacity violations. For the **GRC Full Solution**, the number of capacity violations slightly increases (within 1%) as the focus is on minimisation of the EI, with constraints on delays, and ANSP revenues. In important result is that the capacity is a factor that limits the magnitude of decrease of environmental impact.

- **Cost efficiency**. The direct impact will be on the amount of route charges per flight, a part of direct operational costs. The exact impact (decrease or increase) was assessed for each option of the **Initial Solution** through the validation exercises. Furthermore, the modulation of route charges must be compliant with the revenue neutrality principle, i.e., each ANSP receives the same income for the same amount of workload (measured in service units), within a predefined tolerance. Basically, this follows the current SES performance and charging scheme guidelines. Seen from the airlines' perspective, with the MRC model, the simulation showed that the charges incurred by +70% of the flights would decrease, while -30% would increase. The **Full GRC Solution** produces a slightly higher costs (only fuel, route charges and EI modulation taken into account) with the solution, due to the increased fuel consumption. Which results in about 14% reduction of total environmental impact.

- **Operational efficiency**. The **Initial Solution** options are designed to reduce the CO_2 emissions, mainly through the distance reduction. As the distance is a proxy of the fuel consumption, which in turn is proportional to CO_2 emissions, the solution is expected to decrease the fuel consumption. The simulations demonstrated a 1.54% reduction of flown distance for ECAC flights. On the contrary, the **Full Solution** results in a slight increase in the fuel consumption (about 1%), stemming from the climate hotspot avoidance, as the main objective is the reduction of the total climate impact, not only the CO_2 part. The simulations demonstrated a about 14% reduction in climate impact, which could be further improved when combined with flight level change at tactical level.

- **Environment**. The **Initial Solution** options are designed to reduce CO_2 emissions. As charging has no influence on vertical flight efficiency, this dimension is out of scope, and it is assumed that horizontal distance flown is a proxy of fuel burn and consequently CO_2 emissions. The simulations demonstrated 1.54% reduction of flown distance for ECAC flights. At a further stage, the CO_2 emissions may be assessed, including vertical flight efficiency. The **Full Solution** will not reduce the CO_2 emissions as such, as it is designed to avoid the portions of airspace that can create the highest climate impact (minimising the joint impact of both CO_2 and non-CO_2 effects). The simulations demonstrated about 14% reduction in climate impact, based on the algorithmic Climate Change Functions (aCCF) model. There is a need to assess the total climate impact (both CO_2 and non-CO_2) at the network level, for which there is currently no commonly accepted indicator. The measurement of environmental impact at network level still needs to be researched, also building on the on-going scientific climate research.

4.3 Safety assumptions

The GRC Solutions do not impact safety as they are geared towards the strategic, route charging changes. Only the Full GRC Solution might impact tactical operations, in terms of route choice only. The rest of the operational management is assumed to remain the same as today.

4.4 Regulatory assumptions

The **Initial Solution** options would have an impact, likely minimal, on the current regulatory set-up around route charges, as listed in section 3.2.4.

The subject of the regulatory implications of the modulation of charges concept is complex and despite being available since 2013 in the SES Regulatory Framework, no Member State has implemented it to date.

The **Full Solution** would require a substantial change to the current regulatory setting, considering the novelty of the approach and the related indicators. The Regulation (EU) 2024/2803 (the SES2+ regulation) that was adopted on 23 October 2024 states the following on the establishment of (environmental) charges:

"5. The Commission shall, in consultation with the Member States, air traffic service providers and airspace users, **conduct a study** on the contribution of the modulation of charges to the achievement of the objectives of the Single European Sky, defined in Article 1(1) of this Regulation, and of Regulation

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(EU) 2021/1119. This study shall also **assess the feasibility of that modulation** and its impact on air traffic, service provision, administrative costs and stakeholders.

6. The result of the study referred to in paragraph 5 of this Article will provide the essential information for the Commission to determine whether to adopt an implementing act in accordance with Article 48(3), to ensure the uniform application of modulation of en route charges to encourage airspace users to support **improvements in climate and environmental performance** such as the use of the most fuel-efficient available routing, increased use of alternative clean propulsion technologies including sustainable alternative fuels, while maintaining an optimum safety level.

7. The modulation referred to in paragraph 6 shall consist of financial advantages or disadvantages and **shall be revenue neutral for air traffic service providers**" [32].

The Full Solution explores the feasibility of environmental modulation of charges, the topic itself being in line with the regulatory provisions. The main regulatory assumption used in the project is that environmental modulation is allowed. At this TRL level the project is only testing the feasibility.

Furthermore, it shall be noted that the latest Monitoring and Reporting Regulation (MRR)[7] of the Emissions Trading Scheme (ETS) sets an obligation on aircraft operators to report on the non-CO_2 impact of their flights, starting on January 1st, 2025. The models used in the Full Solution for environmental impact assessment are those set in the ETS regulation (aCCFs only), and the input data for weather forecast are foreseen to be the same, when available out of the NEATS tool. By end of 2027, the Commission will deliver a report on the results of this reporting mechanism and if appropriate, make a legislative proposal to address non-CO_2 effects of aviation through ETS.

The Full Solution explores **route charging modulation** to decrease the climate impact of aviation. The MRR and ETS **are not in scope** of the solution.

However, the consortium would like to flag that having two regulations trying to achieve the same goal would require a careful investigation into the exact goals of each regulation, the impacts of each, and a careful delineation of ultimately adopted goals under each.

[7] Commission Implementing Regulation (EU) 2024/2493 of 23 September 2024 amending Implementing Regulation (EU) 2018/2066 as regards updating the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council

5 References

5.1 Applicable documents

This OSED complies with the requirements set out in the following documents:

Content integration

[1] 'DES Performance Framework, Edition 00.01.04'. Jun. 29, 2023.

[2] 'DES Common Assumptions, Edition 00.02.01'. Jun. 29, 2023.

[3] Content Integration, 'Executive Overview, Edition 00.01', Feb. 2023.

[4] 'DES Performance Framework – U-space Companion Document, Edition 00.01.02', Apr. 2023.

Content development

[5] SESAR 3 Joint Undertaking, 'Communication Guidelines 2022-2027, Edition 0.03', Nov. 2022.

System and service development

Performance management

[6] 'Performance Assessment and Gap Analysis Report (PAGAR) 2019 – updated version, Edition 00.01.00'. May 20, 2021.

[7] 'SESAR Solution Cost Benefit Analysis (CBA) Quick Start Guide (1_0).docx'.

[8] 'SESAR ECO-EVAL Quick Start Guide (1_0).docx'.

[9] 'Performance Assessment and Gap Analysis Report (2019), Edition 00.01.02'. Dec. 13, 2019.

Validation

[10] 'DES HE requirements and validation /demonstration guidelines, Edition 3.00'. Sep. 15, 2023.

[11] 'DES SESAR Maturity Criteria and sub-Criteria_01_01 (1_1).xls'.

System engineering

Safety

[12] 'DES expanded safety reference material (E-SRM), Edition 1.2'. Nov. 17, 2023.

[13] 'Guideline to Applying the Extended Safety Reference Material (E-SRM), Edition 1.1'. Nov. 17, 2023.

Human performance

[14] 'SESAR DES Human Performance Assessment Process TRL0-TRL8, Edition 00.03.01'. [Online]. Available: November 2022.

Environment assessment

[15] 'SESAR Environment Assessment Process, Edition 04.00.00'. Sep. 23, 2019.

Security

Project and programme management

[16] 'Green-GEAR Grant Agreement No. 101114789, version 1'. May 11, 2023.

[17] 'SESAR 3 JU Project Handbook – Programme Execution Framework, Ed. 01.00'. Apr. 11, 2022.

[18] 'Common Taxonomy Description (1_0).pdf, Edition 1.0'. Feb. 07, 2023.

[19] 'Horizon Europe ethics guidelines – essentials_1 (1_0).pptx'.

[20] 'Project Reviews 2024_guidance for IR1 & ER1 (1_0).pptx'.

5.2 Reference documents

[21] Green-GEAR Grant Agreement No. 101114789, version 1'. May 11, 2023.

[22] 'SESAR DES Solutions Green-GEAR V2.0', May 2024.

[23] International Civil Aviation Organization, ICAO's policies on charges for airports and air navigation services (Vol. 9082). International Civil Aviation Organization., Ninth Edition 2012.

[24] Commission Implementing 'Regulation (EU) 2019/317' of 11 February 2019 laying down a performance and charging scheme in the single European sky and repealing Implementing Regulations (EU) No 390/2013 and (EU) No 391/2013 (Text with EEA relevance.), (Regulation 2019/317)'. [Online]. Available: https://eur-lex.europa.eu/eli/reg_impl/2019/317/oj

[25] R. J. Verbeek and H. G. Visser, 'Why aircraft will fly more fuel-efficiently on FRIDAY', 2016.

[26] 'Strategic Allocation of Traffic Using Redistribution in the Network (SATURN) report', 2015. [Online]. Available: https://innaxis-comm.s3.eu-central-1.amazonaws.com/ENGAGE/WIKI/DELIVERABLES/WPE/E+02+33-D05-SATURN-D6+5-Final+Report+(Dissemination)+-V.01.00.00(w).pdf

[27] S. Dietmüller et al., 'A Python library for computing individual and merged non-CO2 algorithmic climate change functions: CLIMaCCF V1.0', Geosci. Model Dev., vol. 16, no. 15, pp. 4405–4425, 2023, doi: https://doi.org/10.5194/gmd-16-4405-2023.

[28] SESAR JU, 'Strategic research and innovation agenda (SRIA)'. [Online]. Available: https://www.sesarju.eu/sites/default/files/documents/reports/SRIA%20Final.pdf

[29] 'Green Deal'. [Online]. Available: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[30] EUROCONTROL, 'Regulation 390/2013 Performance Scheme for Air Navigation Services and Network Functions'. [Online]. Available: https://skybrary.aero/articles/regulation-3902013-performance-scheme-air-navigation-services-and-network-functions

[31] EUROCONTROL, 'Regulation 391/2013 Common Charging Scheme for Air Navigation Services'. [Online]. Available: https://skybrary.aero/articles/regulation-3912013-common-charging-scheme-air-navigation-services

[32] SES2+, European Parliament and Council. Regulation (EU) 2024/2803 of the European Parliament and of the Council of 23 October 2024 on the implementation of the Single European Sky (recast), Official Journal of the European Union, L, vol. 2024/2803, pp. 1–66, 2024

[33] 'European ATM Master Plan'. [Online]. Available: https://www.sesarju.eu/masterplan

[34] 'SESAR 3 ER 1 Green-GEAR – D5.1 – Initial OSED – Green Route Charging', ed. 01.00, 29th June 2024.

[35] 'SESAR 3 ER 1 Green-GEAR – D5.2 – ERP – Green Route Charging', ed. 01.00, 22nd November 2024.

[36] 'SESAR 3 ER 1 Green-GEAR – D5.3 – Intermediate ERR – Green Route Charging', ed 01.00, 12th February 2025

[37] 'SESAR 3 ER 1 Green-GEAR – D5.5 – FRD – Green Route Charging', ed 01.00, submitted 30th June 2025.

[38] 'SESAR 3 ER 1 Green-GEAR – D5.6 – ECO-EVAL – Green Route Charging', ed. 01.00, 9th July 2025.

[39] 'SESAR 3 ER 1 Green-GEAR – D5.7 – Final ERR – Green Route Charging', ed. 01.00, submitted 16th September 2025.

Appendix A Stakeholder identification and benefit impact mechanisms (BIM)

A.1 Stakeholders identification and expectations

Stakeholder	Involvement	Why it matters to the stakeholder
Airline	Planning and operating flights, and paying route charges for ANS services. The GRC Solution should make flight planning more environmentally friendly, through the pricing mechanisms, which should be easily integrated into flight planning software.	The airlines strive to reduce the operating costs, of which the route charges are a part. There are couple of reasons that any change to the route charging is always under scrutiny: • Any increase represents increase in costs, • Any increase in costs should be accompanied by increase in the quality of ANS services, as mandated by performance and charging scheme, and expected by the airlines, • Every change is subject to scrutiny to avoid the possibility of double charging. Reducing environmental impact is important to airlines, as is the reduction of ATFM delays, a portion of which might be reduced through the modulation of charges (initial Solution). Further, the full GRC will look into reduction of the total climate impact, that is rather higher than just the CO_2. It is to be seen if and how the reduction of total climate impact could be set up, and if the benefits are indeed higher than trade-offs.
ANSP	Provision of ANS services on daily bases, staff planning, planning and implementation of investments to better the service provision, traffic forecast, proposal of performance and charging plans.	The ANSPs are paid through the collection of charges, which cover the costs of staff, and investments, aimed at provision of ANS. Any route charging scheme needs to provide enough revenue to cover costs planned in every year of the RP. The safety is primary ANSP concern, but they are also committed to the reduction of environmental impact of aviation. Modulation of route charges (initial Solution) could reduce congestion in certain portions of airspace.

Stakeholder	Involvement	Why it matters to the stakeholder
		The climate hotspot avoidance could make ANS more complex than it is today, as it might divert traffic flows in unexpected ways.
State	Adopts the performance and charging scheme and presents it to the EC.	The performance and charging schemes are regulated and the States are actors in this process. The importance of the charging scheme lies in recovering funds for the ANS provision. If that can be done in such a way that the environmental impact is reduced, even better.
CRCO	Collects route charges from airlines, and redistributes the revenue to the ANSPs. The current process is subject to the performance and charging scheme regulation and Multilateral agreement.	In case the route charging mechanism changes, the process (subject to regulations and agreements) will need to be updated, to redefine the CRCO responsibilities – i.e., detail how the process changes and what it means for CRCO functions.
NM	NM optimise traffic flows by constantly balancing capacity supply and demand while ensuring the safe and efficient operation of flights going to and over Europe	A different route charging mechanism could change the traffic flows. MRC and ODC+MRC are designed to take the capacity into account when setting the modulation charges, which could diminish a part of the capacity related ATFM regulations. The impact of the Full GRC would probably have more impact as it is harder to predict the state of the atmosphere.
Central planner	The GRC Solution would require a set-up of such a function, which could be assigned to one of the stakeholders, it is not necessary to be standalone stakeholder.	The Central planner would collect the traffic and capacity forecasts, and unit rates and run the GRC model/s to determine the modulation factors M. The Full GRC Solution will require the Central planner to share the state-of-atmosphere forecast and collect the post-operational data for route charges assessment.
MET Provider	The MET providers would issue weather forecast, or NWPs, for the determination of climate hotspots and the subsequent definition of the EI charge (strategically).	This would be a new or updated service for MET providers.

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Stakeholder	Involvement	Why it matters to the stakeholder
Society	Society creates environmental impact through their travel behaviour.	The reduced climate impact from aviation brings benefits to the society.

Table 6: stakeholders' expectations and involvement.

A.2 Benefits impact mechanisms (BIM)

This section contains benefits impact mechanisms identified for the GRC Solution options. Both mechanisms would impact the AUs' route choice, which in the price signal contains the capacity considerations and the need for the revenue neutrality.

The Figure 13 depicts the benefits mechanisms identified for **Initial GRC Solution options**.

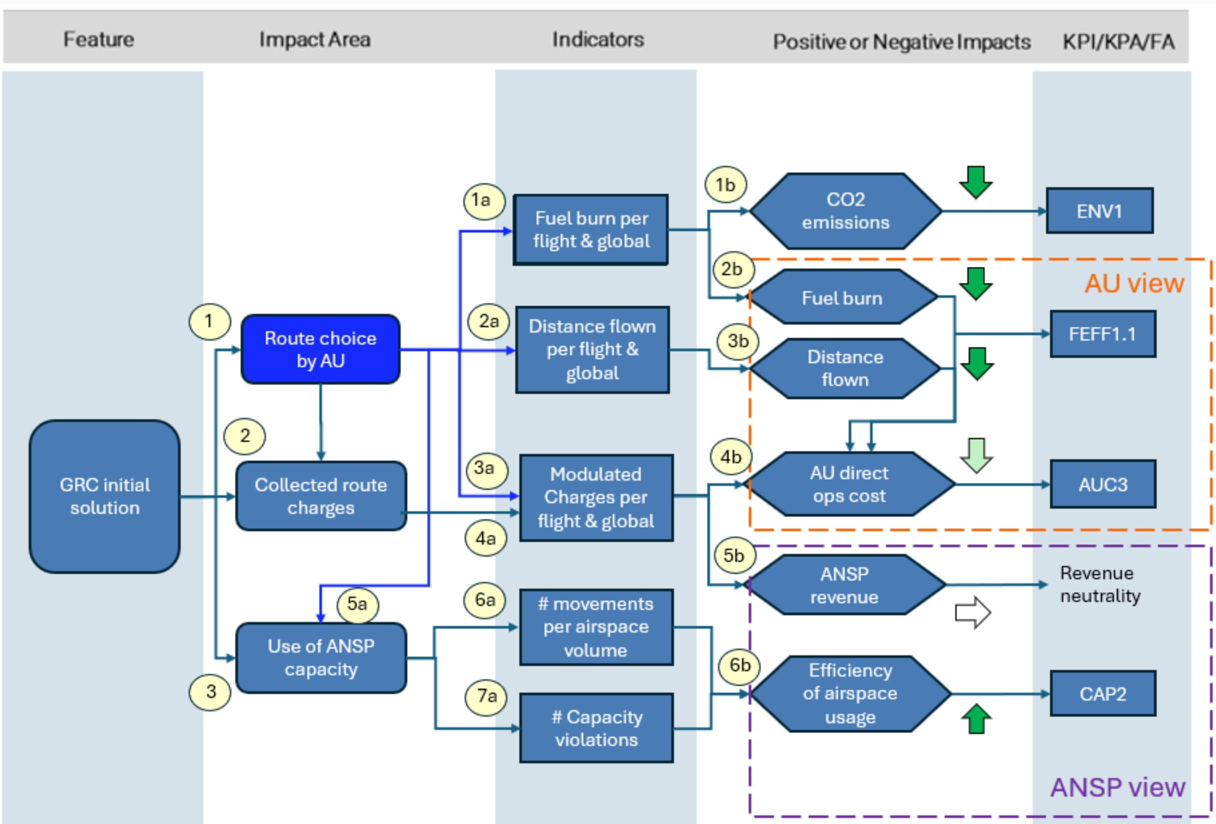

Figure 13 Benefits impact mechanism for Initial GRC Solution.

Feature description:
(1) The GRC initial solution offers route options for AU when filling their flight plan.
(2) The GRC initial solution uses the modulation of charges to incentivise lower environmental impact of flying.
(3) The GRC initial solution impacts the way ANSP available capacity is used by proposing routes that avoid congested areas.

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(1a) Due to AU choosing more environmentally efficient routes, fuel burn will decrease on average per flight, and at network level overall.
(2a) Due to AU choosing more environmentally efficient routes, distance flown will decrease on average per flight, and at network level overall.
(3a) Modulated charges will be applied per flight, at an individual level.
(4a) Modulation will be applied in a way that revenue neutrality is respected at global level.
(5a) The route choice made by the AU with the GRC solution will impact the use of available capacity.
(6a) Due to the GRC proposing routes that avoid congested areas whenever possible, the number of movements per airspace volume will decrease in congested areas.
(7a) Due to the GRC proposing routes that avoid congested areas whenever possible, the number of capacity violations will decrease.
(1b) The reduction of fuel burnt per flight and overall will have a direct impact on CO_2 emissions, which impacts positively the ENV1 KPI.
(2b) The reduction of fuel burnt per flight will have a positive impact on AU direct costs, which impacts positively the FEFF1.1 KPI.
(3b) The reduction in flown distance per flight will have a positive impact on AU direct costs, which impacts positively the FEFF1.1 KPI.
(4b) The application of modulation of charges will have an impact on AU direct costs, which will be slightly reduced according to the simulations, and which impacts positively the AUC3 KPI.
(5b) By construction, the GRC solution will preserve the ANSP revenue overall, in line with the revenue neutrality principle.
(6b) The efficiency of airspace use will improve thanks to the reduction of demand-capacity imbalances at an early stage, which impacts positively the CAP2 KPI.

In summary:
In the GRC initial solution, by capacity being taken into account in the route charge (i.e. price) setting, the expectation is that the number of flights planned to cross a certain sector in a certain time period would be aligned with its capacity. The KPI used in the assessment is *CAP2 The total number (and percentage) of movements per volume of En-Route airspace per hour for specific traffic mix and density (Very High, High and Medium Complexity) at peak demand hours* [13]. As the expectation is that the price signal takes into account the capacity availability, it is expected that the number of flights planned to cross the sectors at specific time periods will be lower than today. The expectation is that the CAP2 will be lower than today (as measured), which does not mean that the capacity will be lower, but that the demand will be in line with the declared capacity.

The cost efficiency to be measured will be on the direct costs to AUs (i.e. fuel and route charges), as the mechanisms are designed to minimise the distance, and as such the fuel and route charges. Furthermore, the modulation of route charges must be compliant with the revenue neutrality principle, i.e., each ANSP receives the same income for the same amount of workload (measured in service units), within a predefined tolerance.

Operational efficiency. The **Initial Solution** options are designed to reduce the CO_2 emissions, mainly through the distance reduction. As the distance is proportional to the fuel consumption, which in turn is proportional to CO_2 emissions, we expect to decrease the fuel consumption (which will be assessed).

As the **Initial Solution** options are designed to reduce the CO_2 emissions, and we expect to see the reduction in that key performance indicator.

The Figure 14 depicts the benefits mechanisms identified for **Full GRC Solution options**.

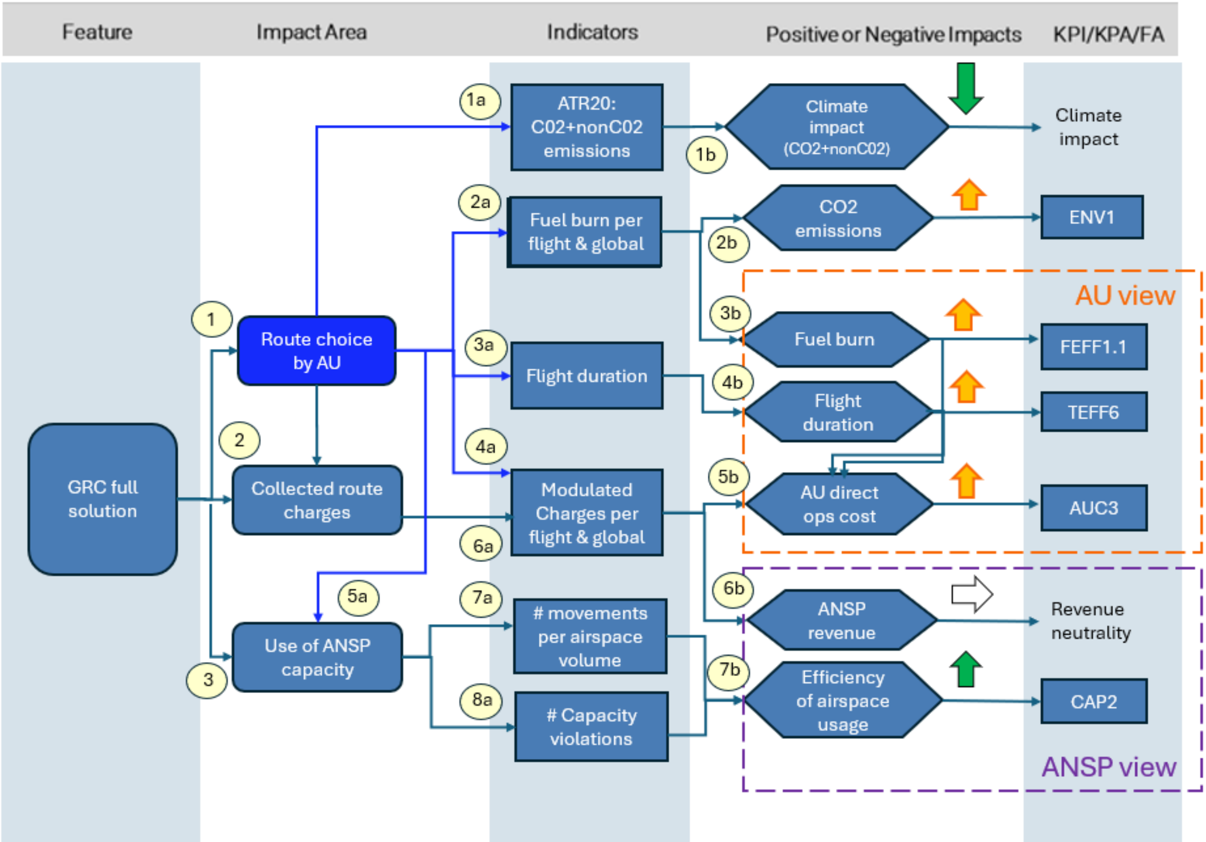

Figure 14 Benefits impact mechanism (draft) Full GRC Solution.

Feature description:

(1) The GRC full solution modulates charges along different route options for AU when filling their flight plan and rerouting adaptations when climate hotspots are forecasted.

(2) The GRC full solution uses the modulation of charges to incentivise lower environmental impact of flying, including an EI rate mechanism that compensates AU for avoiding hotspots.

(3) The GRC full solution impacts the way ANSP available capacity is used by proposing routes that avoid congested areas and options to circumnavigate hotspot areas where flying would generate non-CO_2 emissions.

(1a) With the GRC full solution, on average, the AUs will choose routes that optimise the overall environmental impact (measured with the ATR20 indicator).

(2a) Because the GRC full solution optimises the total environmental effect, this will be slightly detrimental to the average fuel burnt per flight and the fuel burnt overall, due to the environmental hotspot avoidance.

(3a) For the reason explained in (2a), there will also be a slightly detrimental effect on the average flight duration.

(4a) Modulated charges will be applied per flight, at an individual level.

(5a) The route choice made by the AU with the GRC solution and the avoidance of climate hotspot will impact the use of available capacity.

(6a) Modulation will be applied in a way that revenue neutrality is respected at global level.

(7a) Due to the GRC proposing modulation of charges that lowers route charges on routes that avoid congested areas whenever possible, the number of movements per airspace volume will decrease in congested areas.
(8a) Due to the GRC modulation of charges to avoid climate hotspots, but still taking into account the congestion, the capacity violations will not occur, but the capacity saturation might happen in certain parts of the network.
(1b) The climate impact will decrease, which impacts positively the ATR20 KPI (proposed in the absence of a SESAR KPI).
(2b) The slight increase in fuel burnt per flight will have a slightly negative impact on AU flight efficiency, which impacts the FEFF1.1 KPI (due to climate hotspot avoidance).
(3b) The slight increase in average flight duration will have a slightly negative impact on AU flight efficiency, which impacts the FEFF1.1 KPI (due to climate hotspot avoidance).
(4b) Fuel burnt and flight duration will have a slightly negative impact on AU direct costs, which impacts the AUC3 KPI.
(5b) The application of modulation of charges will have an impact on AU direct costs, which will be slightly positive according to the simulations, and which impacts positively the AUC3 KPI.
(6b) By construction, the GRC solution will preserve the ANSP revenue overall, in line with the revenue neutrality principle.
(7b) The efficiency of airspace use will improve thanks to the reduction of demand-capacity imbalances at an early stage, which impacts positively the CAP2 KPI.

In summary:
The GRC full solution mechanism has very dynamic impact on capacity, and the validations show slight capacity saturation at points of network tested. Regarding operational efficiency the Full GRC Solution causes a slight increase in fuel consumption (<1%), stemming from the climate hotspot avoidance, as the main objective is the reduction of the total climate impact, not only the CO_2 part.

The Full GRC Solution does not reduce CO_2 emissions themselves, as it is designed to avoid the portions of airspace that can create high climate impact (minimising the impact of the joint impact of both CO_2 and non-CO_2 effects). The total climate impact is reduced by ~14% at the network level, as measured by ATR20 indicator.

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